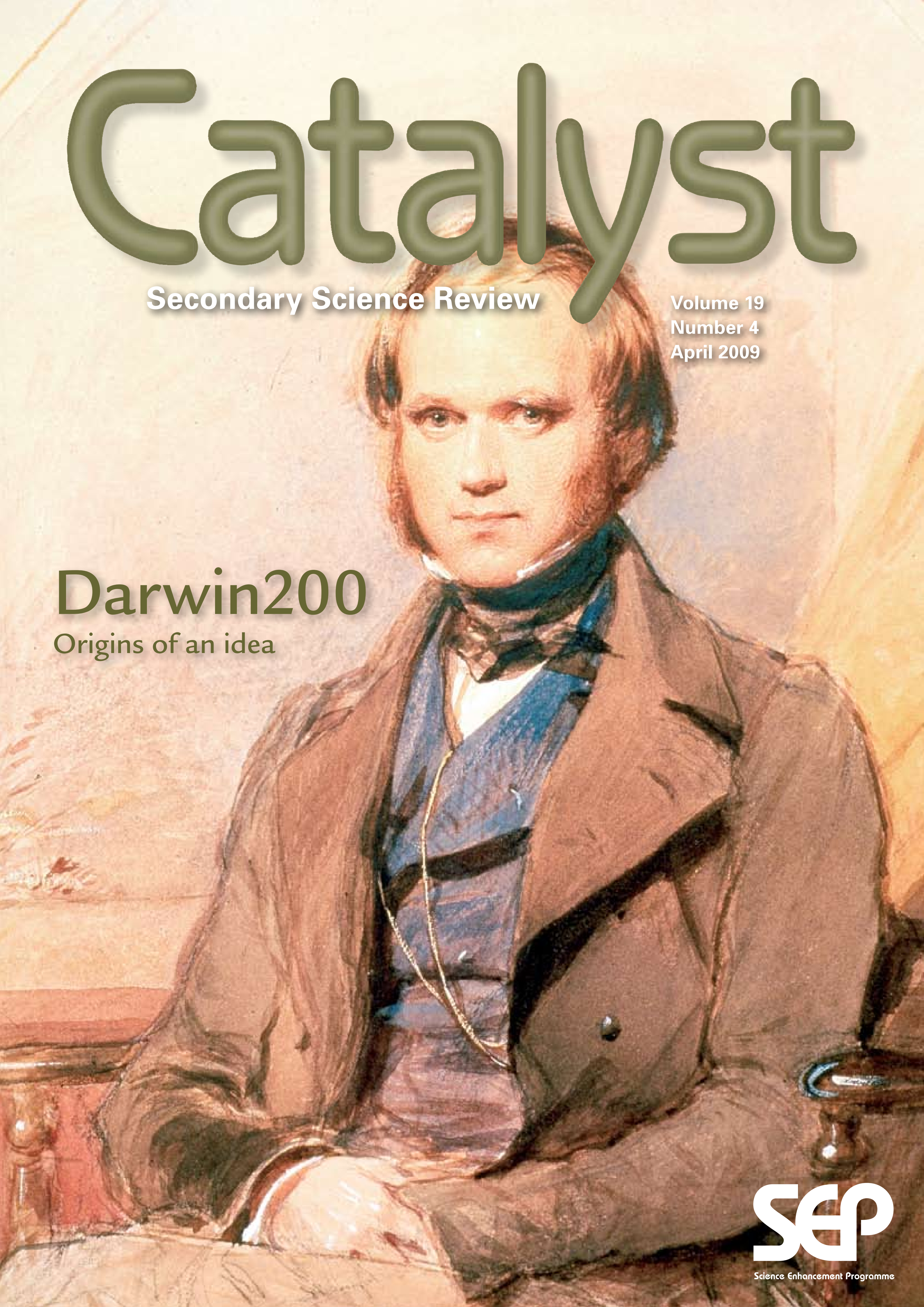
# Catalyst

Secondary Science Review

Volume 19
Number 4
April 2009



## Darwin200
Origins of an idea

SEP
Science Enhancement Programme

# Catalyst

Volume 19 Number 4 April 2009


## Contents



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Individual annual subscriptions (4 issues) are available from SEP for £16.95. Bulk subscriptions (10 copies of each of 4 issues for £75) are also available from SEP. Visit www.sep.org.uk/catalyst/catalystbuy.asp for further details, or email subscriptions@sep.org.uk.


*The front cover shows a portrait of Charles Darwin painted by George Richmond in 1840, when Darwin was 31. (Science Source / SPL)*

## Darwin's bicentenary

2009 marks the bicentenary of Charles Darwin's birth and the 150th anniversary of the publication of his most revolutionary work, *On the Origin of Species by Means of Natural Selection*. In this book, Darwin set out the reasoning which led to his explanation of the way in which evolution occurs.


Darwin is often represented as a fine old Victorian gentleman, as in the £2 coin left. However, as the front cover shows, even Darwin was young once. He was just 22 years old when he decided to join the Beagle on its five-year journey around the world. He planned to become a church minister on his return. That trip turned out to be the ultimate gap year. He studied animals, birds, plants, people and rocks, and the book he wrote on his return became a bestseller.

There are those who say that his ideas about evolution are 'just a theory'. This is to seriously underestimate them. Evolution by natural selection is a theory which comes supported by over 150 years of evidence. It has been tested endlessly, without failing. The more we know about genetics, for example, the greater does Darwin's achievement appear to be.

And now, as Peter J Bentley describes on pages 15-17, Darwin's ideas are being put to work in computers – and they work there, too!

Images from Darwin's published works are reproduced with permission from John van Wyhe ed., The Complete Work of Charles Darwin Online (http://darwin-online.org.uk/)


SEP

Published by the Gatsby Science Enhancement Programme
Gatsby Technical Education Projects
Allington House (First Floor)
150 Victoria Street
London SW1E 5AE

The Gatsby Charitable Foundation





ISSN 0958-3629

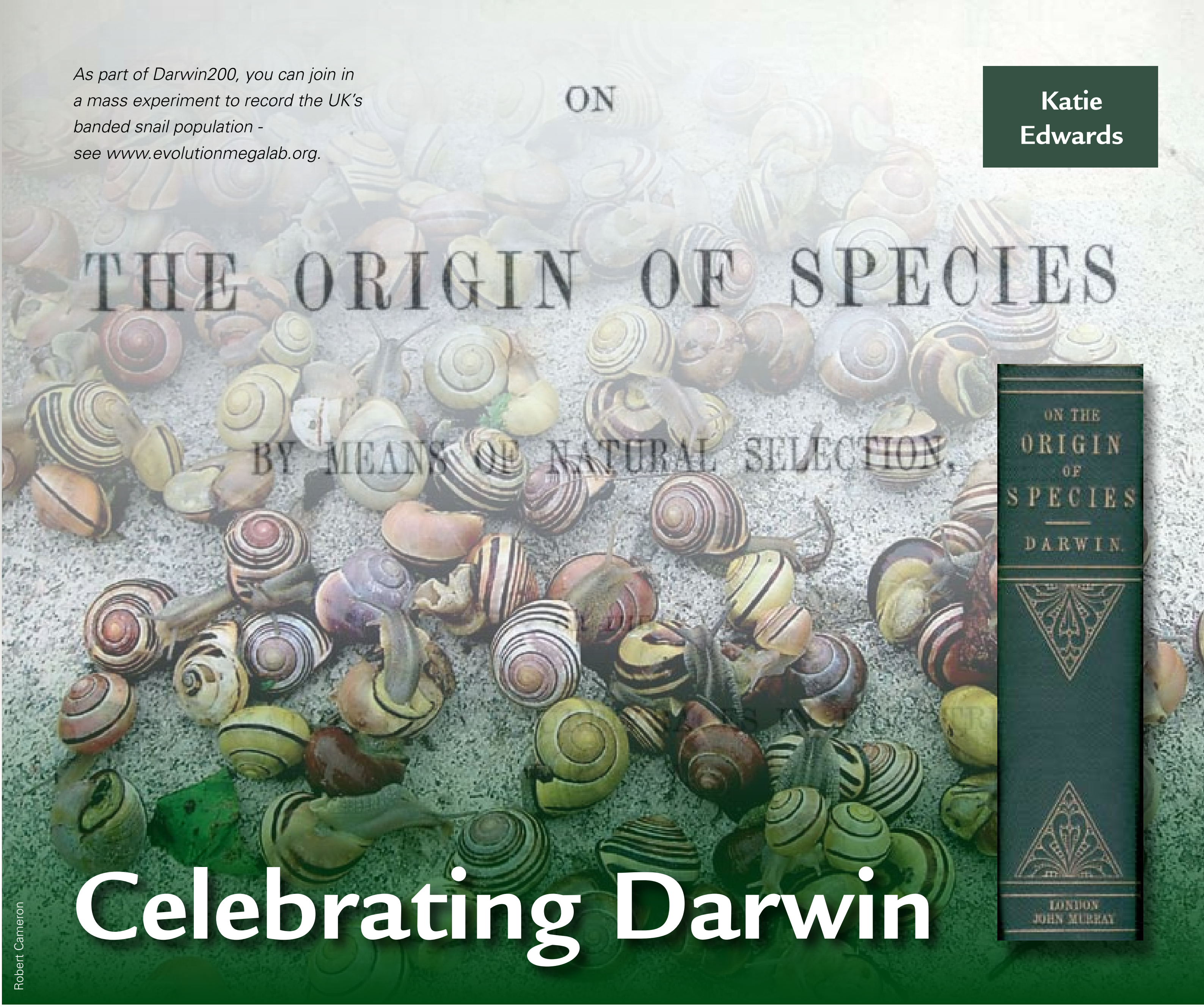
Design and Artwork: Pluma Design
Printed by QCP


## The Catalyst archive

Many articles from this issue of Catalyst, and from earlier issues, are available in pdf format from the SEP website (www.sep.org.uk/catalyst).

*As part of Darwin200, you can join in a mass experiment to record the UK's banded snail population - see www.evolutionmegalab.org.*

Katie Edwards




Robert Cameron

# Celebrating Darwin

*Charles Darwin is the old man with a beard on the back of our 10 pound note. Aside from the royal family, Darwin's face has also appeared on British stamps more than any other person's. He was born 200 years ago on 12 February 1809 and 2009 sees commemorations of the bicentenary of this famous scientist.*


*Royal Mail Darwin commemorative stamps*

Celebrations include workshops to create poems inspired by Darwin, a mass experiment to record the banded snail population, exhibitions about Darwin's life and work, contemporary art shows based on his ideas, new music composed in his honour, walks retracing his footsteps and experiment kits sent to every school in the UK.

The reason he is so well known is because he was the first person to explain why there are so many different types of plants and animals all over the world. He wasn't the first to put forward the concept of evolution – the idea that species gradually change into new species. But Darwin, and his co-discoverer Alfred Russel Wallace, were the first to describe the mechanism for how evolution occurs – a process called natural selection. Darwin wrote out his explanation in his bestselling book, *On the Origin of Species*. When the book was first published 150 years ago, these ideas were shocking because Darwin challenged the accepted views of the time that all plants and animals were created by God and had never changed, and that humans were separate from other creatures.

**Key words**
mutation
evolutionary tree
natural selection

## Darwin essentials

Darwin's core ideas remain as simple as they are elegant. He realised that organisms produce many more offspring than are necessary to maintain a population. He noticed these offspring were not all identical, but they varied slightly, often due to random mutations. He observed that over time organisms with slight advantages for survival would live long enough to reproduce, concluding that, over many generations, this provided a mechanism for species to evolve in response to selection pressures into new forms and varieties. He also deduced, from the examination of geological structures, that the Earth was far older than many, including religious people, thought.


*This tarantula has many offspring, each slightly different from its siblings. This is the variation necessary for natural selection to operate.*

### Box 1 Getting experimental

To celebrate Darwin's genius, every secondary school in the UK will be sent a free experiment kit to demonstrate the principles behind evolution and genetics. Each Survival Rivals kit contains three experiments enabling every student to get practical experience of how evolution works.

I'm a Worm, Get Me Out of Here for 11–14-year-olds explores natural selection by using different-coloured 'worm' baits that are selected and eaten by birds. The 'worm' bait for the experiment is spaghetti coloured with food colouring and students record which coloured bait gets eaten by the birds, and 'breed' the spaghetti according to which colours don't get eaten and so survive.

Brine Date for 14–16-year-olds explores sexual selection by studying brine shrimps in detail, looking at their mating habits and testing hypotheses.

The X-Bacteria for post–16-year-olds looks at antibiotic resistance in bacteria. In the experiment, two strains of bacteria, each resistant to a different antibiotic, are mated. The mated cells are then tested to find out if the antibiotic resistance has been transferred from one strain to the other.

The concept of evolution by natural selection is now stronger than ever, having never been falsified despite 150 years of intensive scientific research, and it has implications well beyond the realm of science. Darwin's ideas have become the framework of modern biological science, reinforced by our more recent understanding of DNA, genes and gene theory, and population genetics. Evolutionary theory now shapes our understanding of contemporary issues as wide-ranging as understanding the consequences of biodiversity loss across the world to modelling the emergence of new strains of the bird flu or Ebola viruses. At its most controversial it has challenged the place of humans in nature, the notion of a Creator and our authority over nature.

## Early days

Charles Darwin was born in Shrewsbury to a wealthy and well-respected family. As a boy he hated school but loved playing outdoors and collecting beetles. Charles and his brother Erasmus did chemistry experiments in a shed in their garden which they called the 'lab'. His father, who was a doctor and wanted Darwin to become a doctor when he grew up, once said to him, 'You care for nothing but shooting, dogs and rat catching and you will be a disgrace to yourself and all your family'.

Darwin set off to follow in his father's footsteps when he went to study medicine at Edinburgh University at the age of 16, but he was horrified at the pain patients suffered when operated on without an anaesthetic, and dropped out after two years. He went on to study theology at Cambridge University with the intention of becoming a country vicar so he could continue enjoying nature. But on completing his degree, when he was just 22 years old, he had the opportunity to travel around the world, working as a naturalist on a ship called the Beagle.


*The route of the Beagle*

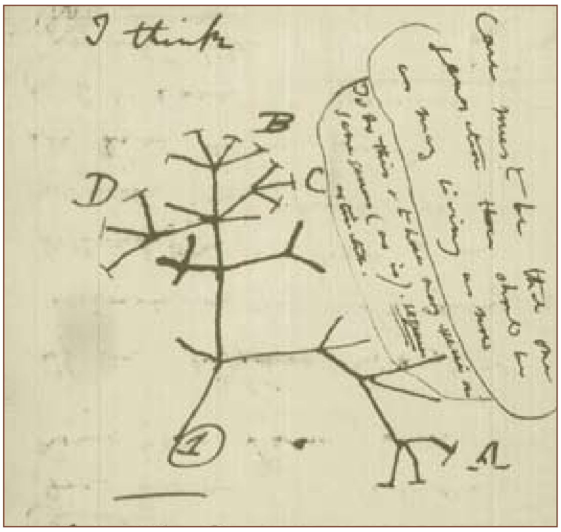
The voyage lasted five years and changed the course of his life. The ship travelled around the coast of South America, stopped at the Galápagos Islands, sailed along the southern coast of Australia and across to Mauritius, then around the southern tip of South Africa before returning to Falmouth. Along the way he was intrigued by, and collected, thousands of exotic plants, animals and fossils that had never been seen before in Victorian Britain. It was when he was visiting the Galápagos Islands, off the coast of

South America, that he noticed the similarities and differences between the mockingbirds on different islands. (He later wrote about the famous Galápagos finches which he only found out about on his return to England.) This set him thinking about how new types of animals evolve.

*Three species of mockingbird from the Galápagos Islands. Darwin sought to explain how separate species like these could have evolved from a common ancestor.*

## Sketching thoughts

Just six months after returning from the voyage, Darwin first sketched his idea that all living things are related and have a common ancestor with a diagram of an evolutionary tree under the words, 'I think'. He spent the next 20 years studying the specimens he had collected on the voyage and accumulating evidence until he was confident that he could go public and announce his theory to the world.




Darwin was a scientist but he never worked in a laboratory as he did all of his experiments in his home and garden in Kent. And he often let his many children – he had 10 although only seven survived to become adults – help him. He tested his ideas with a variety of simple but innovative experiments. He soaked seeds in salt water to see if they would still grow into healthy plants if they had floated across the sea from one island to another. He grew seedlings through pegs to measure the strength of their shoots and scrutinised climbing plants to understand how they moved. Darwin studied domesticated animals to find out how characteristics were passed on to new generations and he kept fancy pigeons in a shed in the garden so that he could record which features they passed on to their young. He even played the bassoon to earthworms kept in pots of earth in his study to see if they moved towards the music.


*The greenhouse at Down House in Kent where Darwin carried out many experiments on plants, worms etc.*

## Darwin facts

- Darwin in north Australia was named in his honour by two of Darwin's former shipmates who led the Beagle's next voyage.
- 'Survival of the fittest' was not a phrase coined by Darwin. He borrowed it from the economist Herbert Spencer, on Wallace's advice. It does not appear in *On the Origin of Species* until the fifth edition.
- Despite being best known for his contribution to biology, Darwin was also a keen geologist.
- He forged his reputation as a biologist in a paper about the entire group of living and fossil barnacles – the product of eight years' study – after he was inspired by specimens he collected off the coast of Chile (see CATALYST vol 18 issue 3).
- Darwin was a prolific letter writer. In his lifetime, he sent around 14 500, including many to respected scientists including Joseph Hooker, Charles Lyell and Asa Gray.
- Darwin cultivated 54 varieties of gooseberry and many varieties of peas, cabbages and beans for his research on the diversity of species.

***Katie Edwards** designs exhibitions at the Natural History Museum, London.*

## Look here!

Find out what's going on in Darwin200 year:
*www.lifesci.ucsb.edu/~biolum/*

See all of his works online:
*darwin-online.org.uk*

Gary Skinner

# A box of beetles

*The photograph opposite shows one of Charles Darwin's collections of beetles. Beetle-collecting was something of a craze in the early 19th century; at the same time, scientific understanding of these creatures grew rapidly.*

Charles Darwin's interest in Natural History began when he was very young, but it was with the beetles that it really first flowered, when he was at Cambridge University. In his autobiography he remarked of that time:

*"But no pursuit at Cambridge was followed with nearly so much eagerness or gave me so much pleasure as collecting beetles. It was the mere passion for collecting, for I did not dissect them and rarely compared their external characters with published descriptions, but got them named anyhow. I will give a proof of my zeal: one day, on tearing off some old bark, I saw two rare beetles and seized one in each hand; then I saw a third and new kind, which I could not bear to lose, so that I popped the one which I held in my right hand into my mouth. Alas it ejected some intensely acrid fluid, which burnt my tongue so that I was forced to spit the beetle out, which was lost, as well as the third one.*

*I got some very rare species. No poet ever felt more delight at seeing his first poem published than I did at seeing in Stephen's Illustrations of British Insects the magic words "captured by C. Darwin, Esq."*

Here we see how Darwin identified his specimens, and we take a look at three interesting specimens from his collection.


*Beetlemania: some of Darwin's fellow students at Cambridge joined him in his beetle hunts; others mocked him.*

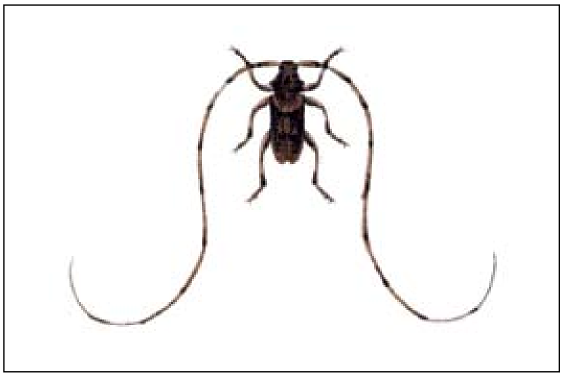
## Know your beetles

To identify his beetles Darwin used a variety of handbooks.

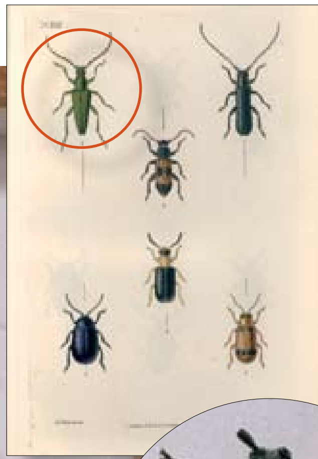
*Cassida* is a so-called tortoise beetle, unmistakable as they are like no other species in this country. They are well armoured, like a tortoise, with the head hidden under the semicircular thorax. This is a beetle which, unusually, is much less colourful when alive than after death. In most beetles the exoskeleton, including the hard wing cases (elytra), retain their colour, which is not due to a pigment but caused by fine sculpturing interfering with light. In the tortoise beetles fading does occur.

*Timarcha* is a beetle commonly known as the bloody-nosed beetle because of its habit of 'bleeding' a red fluid from its mouth and joints, when handled. This is a defence mechanism against predators, the beetle itself being a member of the entirely herbivorous family of beetles called the chrysomelidae or leaf beetles.

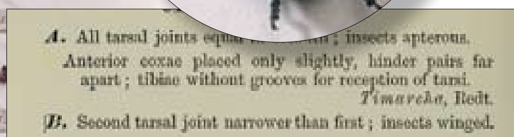
*Saperda* is a member of a group called the longhorns because of their very long antennae, up to 5 times the length of the body in some such as the timberman beetle, *Acanthocinus aedilis*. Many of these beetles are pests of stored timber because their larvae eat wood. They can even do serious damage to living wood in some cases.



Timberman beetle, *Acanthocinus aedilis*.



*The* Saperda *beetle, as shown in JF Stephens'* Illustrations of British Entomology.

A. All tarsal joints equa… ; insects apterous.
Anterior coxae placed only slightly, hinder pairs far apart; tibiae without grooves for reception of tarsi.
*Timarcha*, Redt.
B. Second tarsal joint narrower than first; insects winged.

*The* Timarcha *beetle, from HE Cox's handbook* Coleoptera *or* Beetles of Great Britain and Ireland *(this was the first systematic key to British beetles, but had no pictures).*


*The* Cassida *beetle in a page from* British Beetles *by John Curtis.*

John Stacey

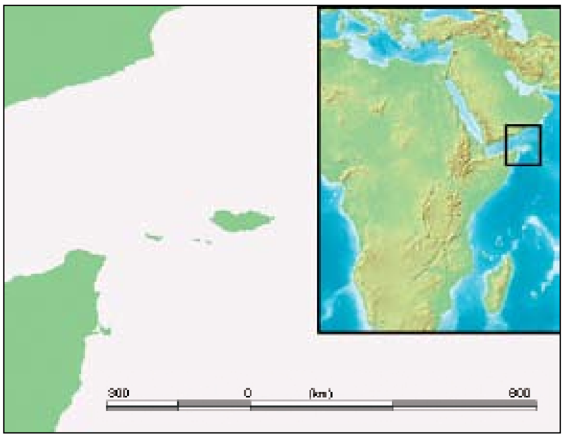
# The Socotra archipelago

## Twenty-first century Galápagos

**Key words**
biodiversity
endemic species
selection pressure

*Socotra is a small archipelago of four islands in the Indian Ocean off the horn of Africa, belonging to the Republic of Yemen. The islands are becoming famous for their range of animal and plant species. John Stacey explains what Charles Darwin might have made of a visit to this wildlife haven.*

The main island has three geographical terrains, narrow coastal plains, a limestone plateau and the Hagghier Mountains. Socotra was recognised by UNESCO as a world heritage site in July 2008. It is considered the 'jewel' of biodiversity in the Arabian sea and has been described as the Galápagos of the East. Socotra is a **biodiversity** 'hotspot', a biogeographic region with a significant reservoir of biodiversity frequently threatened with destruction.



Socotra is in the Indian Ocean, part of the Republic of Yemen.

The Galápagos Islands, which were visited by Darwin, are in the Pacific Ocean and are part of Ecuador.

## Endemic or endangered?

In common with many islands one of the most interesting aspects of the biodiversity is the large number of **endemic species** (Box 2) , (endemism) that have already been identified by a very limited number of scientific surveys. Isolation, heat and drought have encouraged the development of endemism (the presence of species found nowhere else on Earth).

An *endemic* species should not be confused with an *endangered* species, a species with a declining population in danger of extinction, even though it may be found in several places. Some endemic species may also be endangered, usually due to habitat change. This could be caused by expanding human developments or reduction of suitable habitat.

Charles Darwin would have had to have spent some time on either the mainland of the horn of Africa or Yemen to become familiar with the main species of plants and animals. He would have then had to land on Socotra between October and May as even now the island is inaccessible between June and September due to severe monsoon weather. He would have quickly noticed the large number of endemic plant species, with an average density about twice that of the Galápagos archipelago.

| | Land area km² | Plant species | Endemic species |
|---|---|---|---|
| Galápagos archipelago | 7 844 | 543 | 229 (42%) |
| Socotra archipelago | 3 799 | 825 | 307 (37%) |

He would have seen a bird called the Socotra bunting and would have been able to collect and describe its eleven to fourteen subspecies. Subspecies are regarded as an intermediate stage in of the process of speciation, the formation of new species. They are physically distinct but they are capable of interbreeding to produce fertile offspring in areas were their habitats overlap.

The reptiles, especially 15 endemic species of geckos, would also have been of great interest to him.

| Biological group | Number of endemic species |
|---|---|
| plants | 307 |
| insects | 113 |
| reptiles | 26 |
| birds | 6 |

## Darwin gets thinking

On the Galápagos, Darwin noticed some species of Mockingbirds which were different on different islands in the group. It was this observation which got him thinking about how species change. In 'The Voyage of the Beagle' he commented

*"My attention was first thoroughly aroused by comparing together the various specimens ... of the mocking-thrush ..."*

And

*"Although the species are thus peculiar to the archipelago, yet nearly all in their general structure, habits, colour of feathers, and even tone of voice are strictly American."*

And famously

*"It never occurred to me, that the productions of islands only a few miles apart, and placed under the same physical conditions, would be dissimilar. I therefore did not attempt to make a series of specimens from the separate islands. It is the fate of every voyager, when he has just discovered what object in any place is more particularly worthy of his attention, to be hurried from it."*

It seems likely that he would have been encouraged down a similar way of thinking if he had been in the Socotra archipelago rather than the Galápagos one.

In addition to these animals, Darwin would also have been fascinated by the endemic plant genera, of which there are ten. Here are the three most famous and easily seen:

### BOX 1 Natural Selection

Darwin's real achievement was to suggest the simple, but very powerful, idea of Natural Selection. This idea relies on just a few simple steps:

- Living things produce more offspring than are needed to replace themselves, but populations stay about constant.
- Members of a species vary.
- This variation can be passed on (inherited) from parents to offspring.
- Those with advantages tend to survive better and (this is the important point) leave more offspring who carry their advantageous features.

A succulent, the desert rose (*Adenium socotranum*). This has a thickened short perennial stem. It uses cell sap cycling within the caudex (thickened stem) to prevent overheating as a specific adaptation to the arid climatic conditions on Socotra.

The dragon's blood tree (*Dracaena cinnabari*) gives a red sap used as a medicine and a dye.

Photos: Jan Vandorpe

The cucumber tree (*Dendrosicyos socotrana*) is the only member of the cucumber family to grow as a tree. It also has a caudex stem.

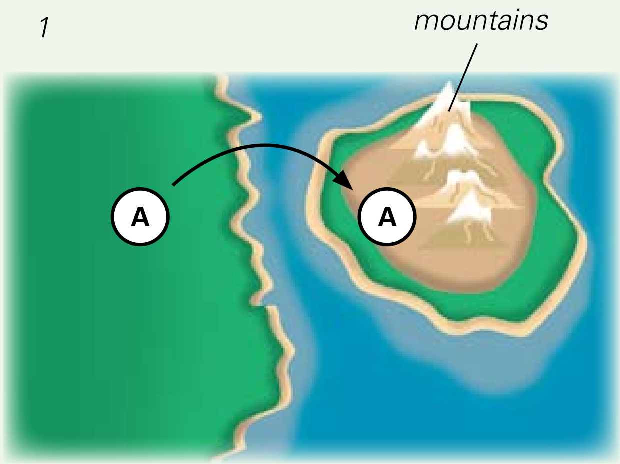
## The future for endemic species on Socotra

So, this island group would have provided Darwin with all the raw material for thought which he got in the Galápagos. And, also like the present day Galápagos, this unique place is under threat from humans. The three unique plants species named above are all under threat of extinction in the wild. A significant number of species are already registered on the IUCN endangered list, even though very little development has taken place on the islands. The expanding population of goats, the sinking of boreholes to obtain water for stock animals, and introduced rat populations predating bird eggs are all exerting pressure on many endemic species.

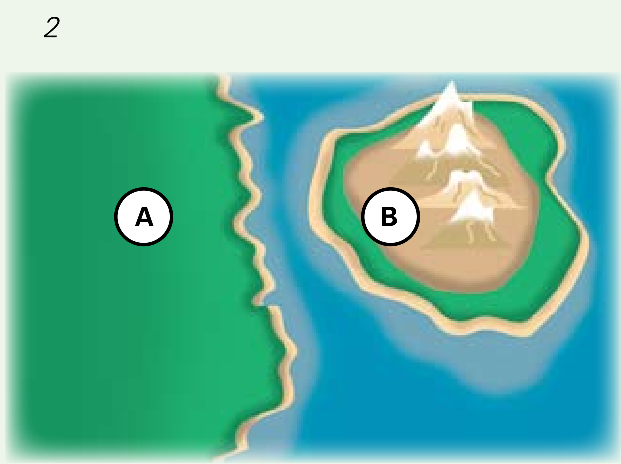
Of the three main habitats the coastal plains are more degraded than the limestone plateau as they are more accessible for humans and livestock. The trees growing further inland are beginning to be threatened by harvesting of fodder for livestock. And there is now an airport on Socotra with one flight a week from the mainland. Ecotourism is just beginning and at present there are very few facilities for visitors. It remains to be seen to what extent visitors to Socotra cause degradation of habitats leading to extinction in the wild.

## BOX 2 Endemism

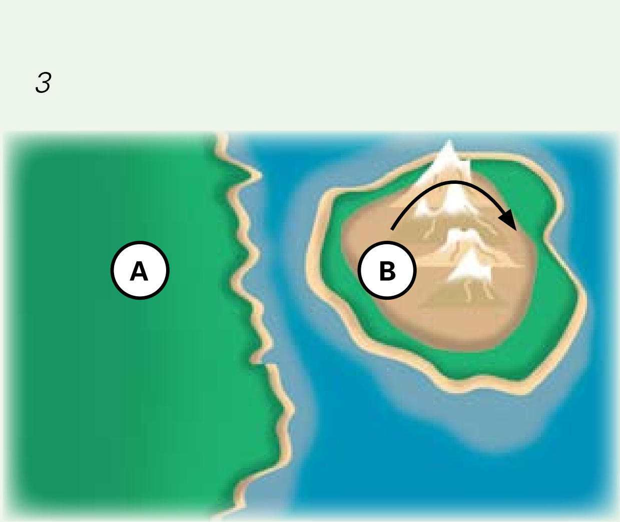
Endemic species may be formed when a small population becomes geographically isolated from a main population, like organisms on an island isolated from those on the mainland. The gene pool of the founder population is likely to be less diverse as the island population will initially be small. The new environment will provide different **selection pressures** (see Box 1) on the individuals favouring the passage of genes which give a selective advantage into the next generation. In addition, some genes will be lost randomly because the founder population is small and they were not passed on to any individuals simply by chance. The genetic, behavioural and structuraal differences become sufficiently different that breeding to produce fertile offspring with members of the ancestral mainland population is not possible.



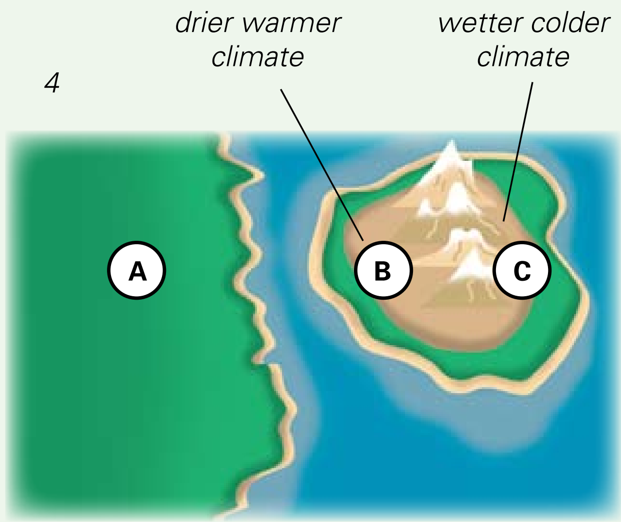

*Some of population A is carried from the mainland to the island.*




*Isolated from population A, the island population eventually evolves to form a new species, B.*




*Some of the population B moves over the mountains to the opposite side of the island.*




*Isolated from population B, a new species, C, evolves due to the different selection pressures on that side of the mountain range.*

The Socotra Archipelago Conservation and Development Programme (SCDP) is an attempt by the Republic of Yemen to conserve and develop in a sustainable way the group of islands with the help of the United Nations Development Programme.

*John Stacey is a biologist based in Rye, Sussex, UK.*

**Look here!**

The SCDP website: *www.socotraisland.org*

Friends of Socotra: *www.friendsofsoqotra.org*

Gary Skinner


Down House, Darwin's home in the village of Downe, Kent, just a 30 minute train ride from central London.

*Much of Charles Darwin's life after his return from the Beagle voyage was spent at Down House in Kent. He moved here in September 1842 and died in one of the bedrooms on 19th April 1882.*

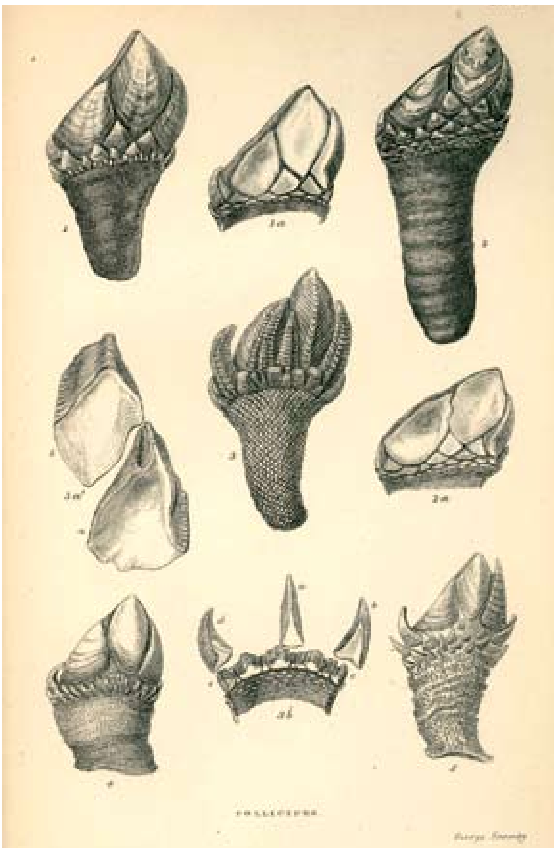
*The Big Picture on pages 10-12 shows Darwin's study roughly as it would have looked during his lifetime. A key to the contents of his study appears on page 13. Here you can read about his life at Down.*

## A day in the life of Charles Darwin at Down House

Most of Darwin's time at Down was spent in 'the Old Study' or out strolling along the Sandwalk. It is remarkable that such an important idea as Darwin's Theory of Evolution by Natural Selection should have been formulated and refined in this study, and largely as a family enterprise. Overleaf you can find a panorama of the Old Study as it has been recreated by English Heritage today. In the key some objects are highlighted and we will use the photograph, the key and some other images to take us through a typical Darwin day.

Charles was an early riser, being outside at sunrise for a short walk. At 7.45 he would breakfast and then go into the study to work until 9.30.

This work might involve writing books or papers or dealing with specimens. For these activities he would use a quill pen 8, and, if parceling up specimens, maybe the string on the spool his son Horace had made him 11. During the years 1846-1854 he would almost certainly work on barnacle dissection during this time, using the instruments shown 10. This work led, in the years 1851-1854, to the publication of a major work on the barnacles (or cirripedes) of the world (see CATALYST vol 18 issue 3, 2008).



Darwin's study of barnacles included detailed observations of the characteristics which distinguished different species.

continued on page 14


*Charles Darwin's study at Down House served as his laboratory and writing room - see key on page 13. Photo: Gary Skinner*

# Darwin's study - Key




1. Map of Caribbean, annotated by Darwin
2. Partition hiding Darwin's privy with bowls, towels and water
3. Dog basket
4. Darwin's walking stick
5. Joseph Hooker, botanist
6. Charles Lyell, geologist
7. Josiah Wedgwood, pottery manufacturer, maternal grandfather
8. Quill pen
9. Microscope
10. Dissecting instruments
11. Spool for string made by son Horace Darwin
12. Pembroke table
13. Darwin's wheeled chair
14. Correspondence
15. Darwin's microscope stool
16. Pill boxes for collecting insects
17. Preserved specimens in spirit
18. Erasmus Darwin, paternal grandfather

continued from page 9

At 9.30 or so, he would go into the drawing room, where he would read letters, or listen to his wife, Emma, reading him a novel. More research followed until 12. This might involve more dissection of specimens which he had been sent from all over the world preserved in spirit 17.

During this time, and because of his lifelong illnesses, he found it convenient to be able to tend to his daily needs in the study. For this purpose he installed a 'privy' with a commode (portable toilet) and hand washing facilities, hidden behind a screen 2.

If he was reading or writing letters he would probably sit in his chair 13. This was specially made for him, with wheels so he could move about without having to stand. He might do this to get to the spittoon or to see who was at the door if he heard the bell ring - he had a mirror positioned so he could do this from the chair. He wrote *The Origin of Species* in this chair, with a board laid across the arms to hold the papers.

For microscope work he would sit on the low stool 15, with the microscope 9 on the window ledge. This stool was also fitted with wheels and Darwin's children used to ride around the dining room on it using one of his walking sticks 4 to push themselves along.


*Darwin's microscope*

At 12.00 Charles would embark on something which he had made a tradition, and which was no doubt very important in allowing him thinking time. Whatever the weather, he would embark on a stroll along the Sandwalk, his 'thinking path', always taking his white terrier Polly 3. On his way he would normally check up on his plants in the greenhouses he had had specially built. He was most interested in orchids and plants that eat insects (carnivorous plants), on which he wrote books in 1862 and 1875 respectively.

At 1 pm he would return to the house and have lunch and read the papers until 2pm. From 2 until 3 he would sit in the chair by the fireplace writing letters 14. Darwin was an inveterate letter writer and we know of over 15 000 which still exist!

Darwin spent most of his life struggling with illnesses, some of which no doubt arose from tropical conditions he encountered on the Beagle voyage 1. By 3pm he would often be very tired


*The Sandwalk at Down House, designed for thinking.*

and would now rest in the bedroom, with his wife Emma reading him more of the novel.

On some days, Darwin would have guests visiting, socially or maybe for professional discussions. Frequent visitors included Joseph Hooker 5, the botanist and Darwin supporter, and Charles Lyell 6, from whose writings Darwin learnt much in his early years.

At 4 pm Charles would emerge from the bedroom and go for another think on an afternoon stroll, returning by 5 for more research on his current project.

This would be followed by further rest and more of the novel, a light dinner and some games of backgammon with his daughter Emma. He kept the scores of all these games in a notebook for many years. At 9 he would finish off his day with some reading of a scientific text, listening to his daughter Emma play the piano and bed at 10.

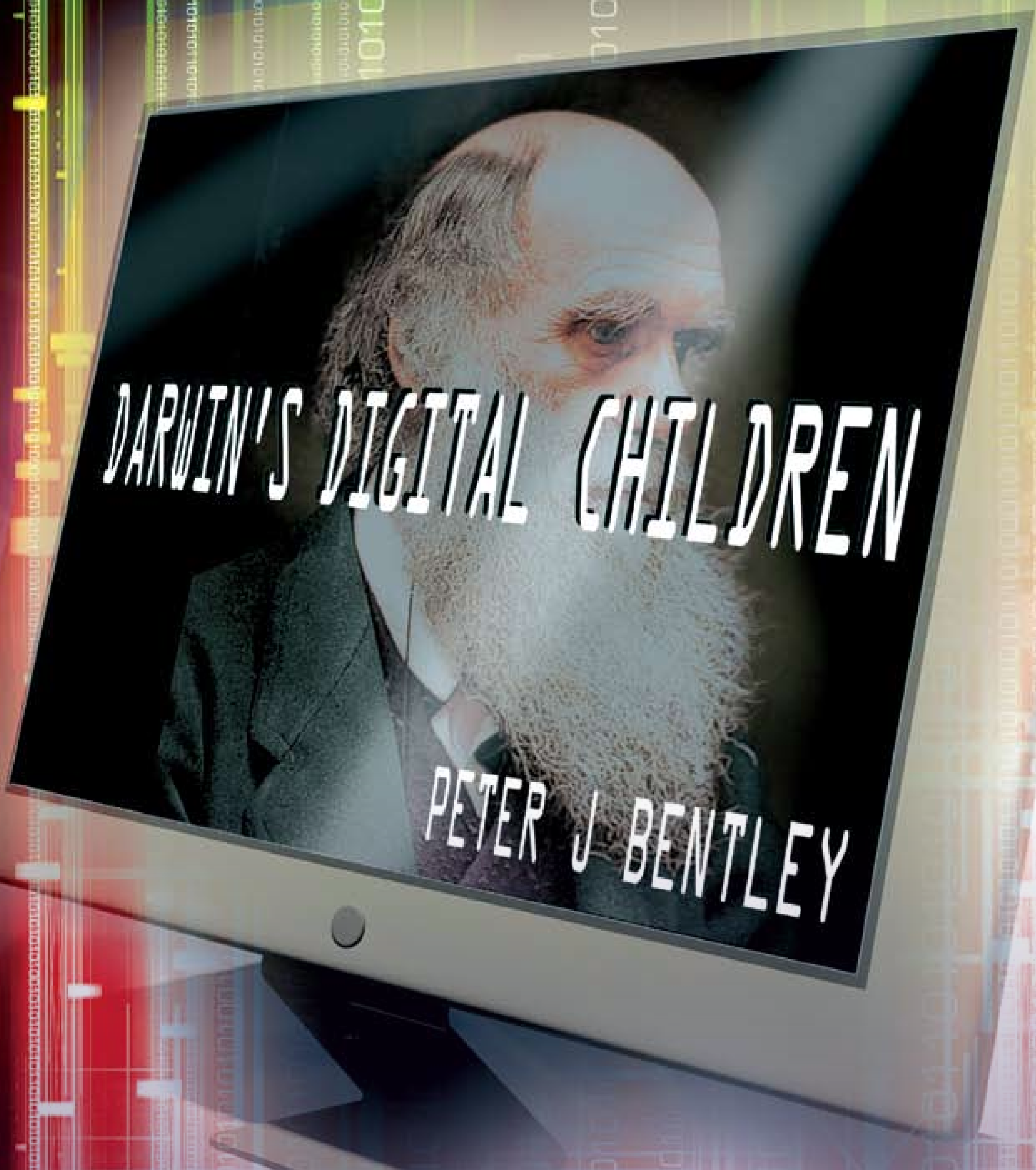
As well as the undoubted quality of Darwin's mind, this routine, with the convenience of his study, garden, greenhouse and Sandwalk, together with his love of correspondence with scientists all over the world, put Charles Darwin in a unique position to formulate what is one of the most important ideas in the history of science.

*This engraving shows Darwin's study as it was shortly after his death.*

*Gary Skinner is biology editor of* CATALYST

**Look here!**

Visiting Down House and virtual tours of its rooms: *www.english-heritage.org.uk/Darwin2009/*



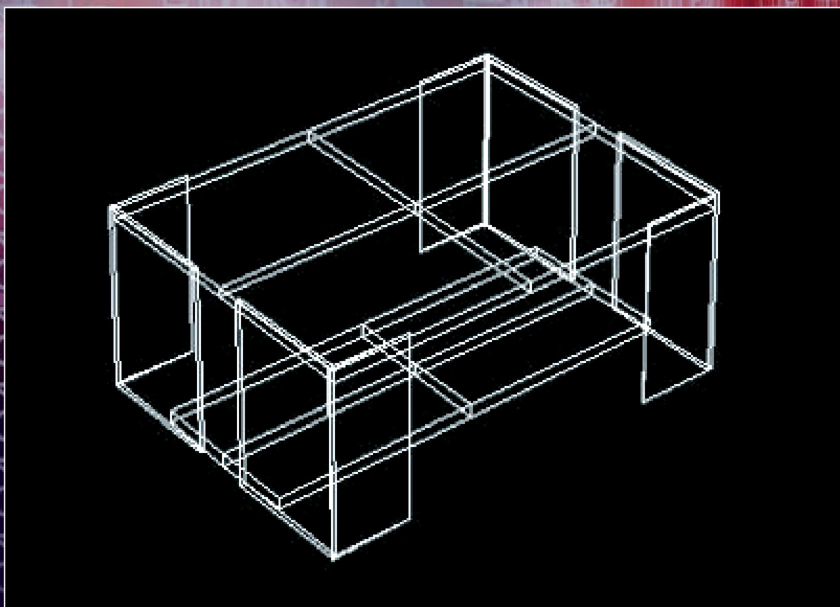



**Key words**
evolution
natural selection
self-replication
mutation

*Computer scientists can use Darwin's ideas to make things evolve in a virtual world. Peter J Bentley, a computer scientist, describes how.*

Darwin is famous because he changed the world. He explained life on our planet. He may have been born 200 years ago and his beard wouldn't win fashion awards, but his idea is just as valid today as it was back then. So if I were to choose a celebrity to meet, it would be Beardy Chas.

I'd like to think Darwin would be astonished if he were sitting next to me right now. OK, he'd probably be astonished at almost everything – the lights, the chairs, the computers – he lived a long time ago. But I'd like to think he would be more astonished when I told him that the coffee table his cup of tea now rested on was not designed by a human. It evolved. I think he would be equally surprised at what I would show him on my computer. I would show him **evolution** happening before his eyes.



*The design for this coffee table was 'evolved' on a computer.*

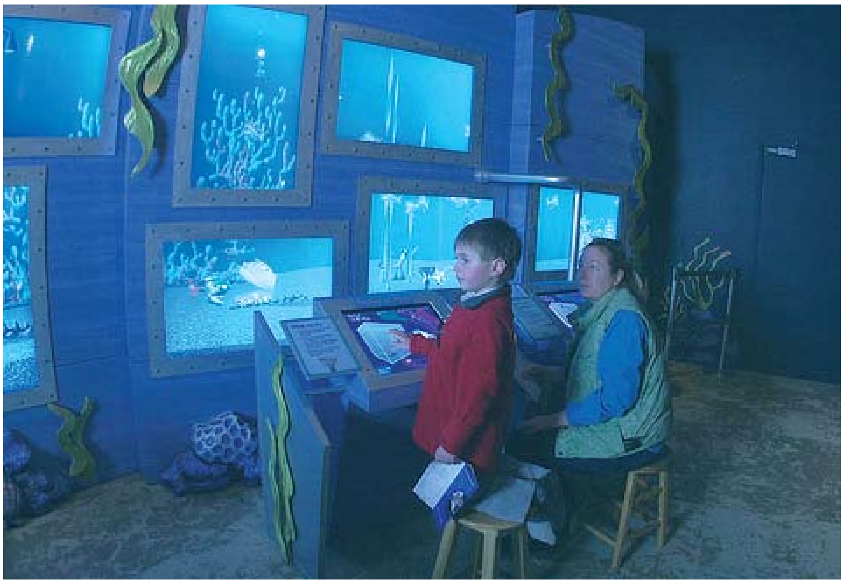
## Evolution by computer

Perhaps you are thinking cynically, "Ah yes. He would show a computer game like *Spore*." Or perhaps you're thinking, "He would show a movie of something evolving like a cartoon or computer animation."

Nope. I would show him real evolution, happening by **natural selection**, the very same process that shaped all life on Earth. Happening live, in front of his eyes. Evolution that I do not control, and that I cannot predict.

I'd show him a view of a virtual world, with a colourful landscape. Virtual clouds would drift overhead, changing the light and the appearance of the colours as the virtual sun was obscured and revealed. He would see hundreds of little crawly things, eating parts of the landscape. As he watched he would see some die and disappear. "They've stupidly eaten something poisonous," I would explain. He'd see others coming together and producing baby crawly things. And as he watched he would see the population change in front of his eyes. Now the little critters can see where they are going – they have eyes! Now they can see what is good and bad to eat. Now they have formed strategies of movement – first they eat in one area, then they migrate to another area and let the first region regrow. Now some have discovered they can eat each other – there are predators and prey!

Then I'd show him another, different virtual world. This one has virtual water and we see strange twitching blobs floating about. As we watch we see that the better-swimming blobs have children; those that cannot swim so well have no children. Over time we see the shapes of these blobs change before our eyes. Generation after generation we see the shapes slowly morph into highly proficient swimmers. Some look amazingly familiar – there's something that looks exactly like a turtle with four flippers propelling itself along. Here's something that looks like a watersnake, spiralling its way through the water.



*This virtual fish tank keeps evolving at the Boston Computer Museum.*

Not a trick, not a game, not a fictional animated movie. These are scientific research projects that study evolution running on a computer. We call them Artificial Life, for obvious reasons. We don't tell them what to do, and we don't control them. Instead we create a virtual world containing food and hazards, and we add the magic ingredient – some simple self-replicating things. Then we watch what happens.

## What makes evolution?

Evolution is a very simple process. You need **self-replication** (things that can make copies of themselves). The kiddies need to inherit features from their parents – so if the mother has a big head, the child may have a big head too. You need the occasional random **mutation** (perhaps the child has a bigger nose than either of its parents). And you need *selection* – something must ensure that some of the things survive longer than others, making them more likely to have kiddies, while others will die young and childless.

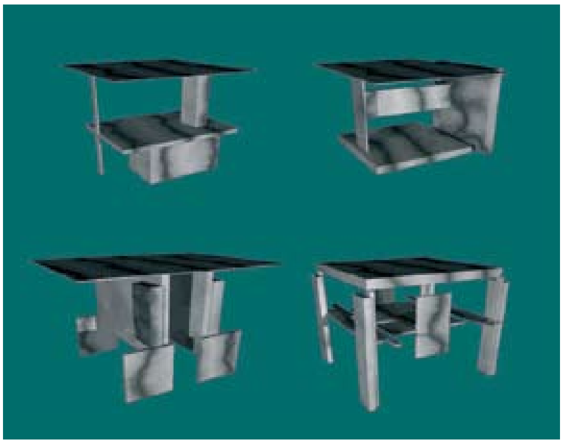
If you've got those things going on, then evolution will happen. It has no choice, it is inevitable. But the exciting thing is that evolution doesn't care what those self-replicating things are made from.

In biology it's all about the genes. When parents have children, the kids inherit their parents' genes. When a mutation happens, that's a random change to a gene. When an organism dies, its genes are lost to future generations unless it managed to have children first. Genes are nothing more than molecular information. Data written into DNA, rather than on a CD-ROM or DVD. But it's all data nonetheless.

In computer science we don't use DNA to store information. Computers are very good at handling information in their electronics rather than in a bag of chemicals. So when I make a virtual world and I drop in those self-replicating things, all I've done is add packets of information that enjoy making copies of themselves. Each packet of information corresponds to a virtual critter – something that exists and interacts with the virtual world. If it's good enough it may survive long enough to make a few copies, if not, it won't. And so generation by generation, the packets of information evolve.

## The evolving table

For example, let's say I was evolving a coffee table. Each packet of information represents a possible table design. Some are great, but some are bad, looking more like a pile of bricks or a giant screwed-up ball of paper. Each design can be judged – how well does it function as a table? (Does it support objects at a consistent height without falling over? Is it the right size while being light enough to move?) The better designs have 'children' – new designs which inherit a random mix of the parameter values that make up the parents, plus a little random variation. The worse designs are removed from the population. So each generation contains table designs only derived from the best of the previous generation. After a few hundred generations, we have a very good evolved coffee table design.



*Four coffee table designs – but which will prove to be the fittest?*

Even though I may have created the virtual world, and the first simple self-replicating packet of information, I have no idea exactly what it will become. So every time I ask it to evolve a new coffee table, I will see a new design that solves the problem in a different way.

Perhaps you're thinking: evolution is surely enormously slow. But speed is relative. Elephants take a long time to get around to having kids, so their generations last a while. They evolve slowly. Bacteria and viruses reproduce in minutes, not years, which is why we are forever catching the flu and colds – they keep evolving into new varieties every few months. Bacteria are quick, but computers are *much* faster. A computer can have a population of millions of packets of information, with each generation lasting a tiny fraction of a second. We can see the entire evolutionary history of an artificial organism in seconds.

So computers can evolve information (and coffee tables), and information is used for *everything*. You want to compose a piece of music? That's just mp3 data. An image is just a jpeg file. You want to draw a design for something, make a timetable, figure out how to maximise your cash? All just data, so we can evolve it all! We can evolve music, art, designs, timetables, schedules, financial plans. We can evolve brains and bodies of robots, better components for engines. We can even evolve new computers!

I'm a computer scientist at UCL and, like several hundred other scientists around the world, I evolve solutions to problems every day. My furniture at home was evolved by my computer. I've evolved music and art. I've evolved designs for new electronic circuits, robots, hospital designs. I'm no good at creating any of those things – I just tell my computer what I want and it evolves it for me.

So if Darwin was sitting next to me I'd be able to explain this to him. His theory of evolution is not just a theory any more. It's a technology. We exploit it every day for an astonishing variety of products, including my coffee table. Darwin is going to stay famous for a long time, and rightly so.

***Dr Peter J Bentley** is a senior research fellow at University College London and author of* The Undercover Scientist *and* The Book of Numbers. *His website is at http://www.peterjbentley.com*

## Australia's new flowers

Jon McCormack is an Australian artist and computer scientist. He has written the software which evolves the striking virtual flowers which you see here. You can see more of his work at www.csse.monash.edu.au/~jonmc/art.html.

*Jon McCormack's works in a street installation at Queensland University of Technology*

NASA

Philip Ball

# $H_2O$

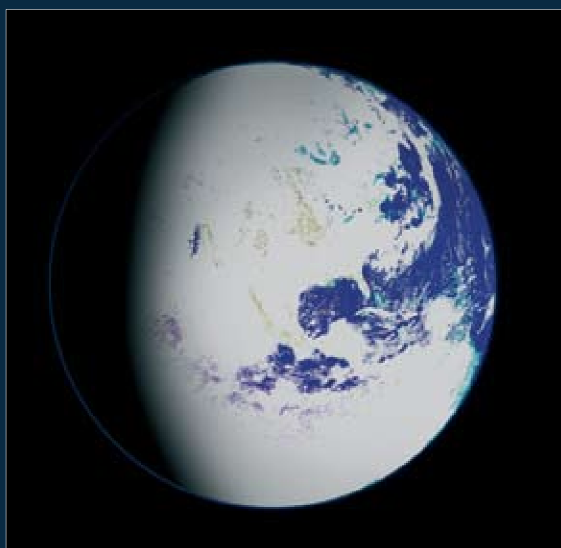
**Key words**
hydrogen bond
phase
heat capacity
pathological science

## Hot ice and the mysteries of water

*Water, ice, steam – they are all $H_2O$. Water is everywhere, so you might think that scientists would understand everything about this apparently simple substance. But water is complicated, even mysterious, as Philip Ball explains.*

In Kurt Vonnegut's 1963 novel Cat's Cradle, the world is devastated by an environmental catastrophe as all the oceans turn to ice: 'The moist green world was a blue-white pearl.'

Some scientists suspect a similar thing really happened around 700 million years ago, when the Earth's climate cooled down and the ice sheets grew past some critical 'tipping point'. Because bright ice reflects the Sun's rays back into space whereas the dark seas absorb them, more ice cover means less heat received from the Sun, and there could be a positive feedback process that leads the ice to just keep growing until it covers virtually the whole globe: a scenario called the Snowball Earth.



*A computer-generated image of the Snowball Earth scenario. Hundreds of millions of years ago, most of the Earth's surface may have been covered in a thick layer of ice. Most living species died out but those which survived exploded into evolutionary diversity.*

But Vonnegut's icy Earth was worse than that. In his book, the oceans are not covered in ice but frozen solid from top to bottom. And it's no ordinary ice like the stuff in summer drinks or glaciers and ice caps. It was a fictional type called ice-nine, discovered by a scientist named Felix Hoenikker, which freezes at 114.4°C – well above water's usual boiling point of 100°C.

So ice-nine stays resolutely frozen at the ordinary temperatures on the Earth's surface. And Vonnegut explains that if a speck of ice-nine comes into contact with ordinary water, it will act as a seed that rearranges the water molecules into the pattern of ice-nine, so that the seed will grow and grow, just like a crystal of ice spreading through a puddle on a cold winter night. All water that touches ice-nine becomes ice-nine itself. And that's inevitably what happens, as a shard of Hoenikker's ice-nine eventually falls into the sea.

## Fourteen phases

But of course, there's no such thing as ice-nine, right? Wrong. There are, at the latest count, something like 14 different forms of ice, and one of them is ice-nine, or ice-IX. Ah, but it's not the stuff that Vonnegut imagined – it melts at around minus 100°C, and exists only if ordinary ice is squeezed to several thousand times atmospheric pressure. Yet ice that stays frozen up to 100°C and beyond does exist. It is not ice-nine but ice-seven (ice-VII), and it is very hard and dense.

The catch is that ice-VII, like all the forms of ice other than the familiar ice-I we know from snowflakes and freezers, can exist only at high pressures. All the same, this proliferation of ices is very unusual. Most substances have only one or a few solid forms (called phases), which may be interconverted by changes of temperature or pressure. Generally speaking, squeezing favours the formation of denser solid phases, where the atoms or molecules are packed together more compactly.

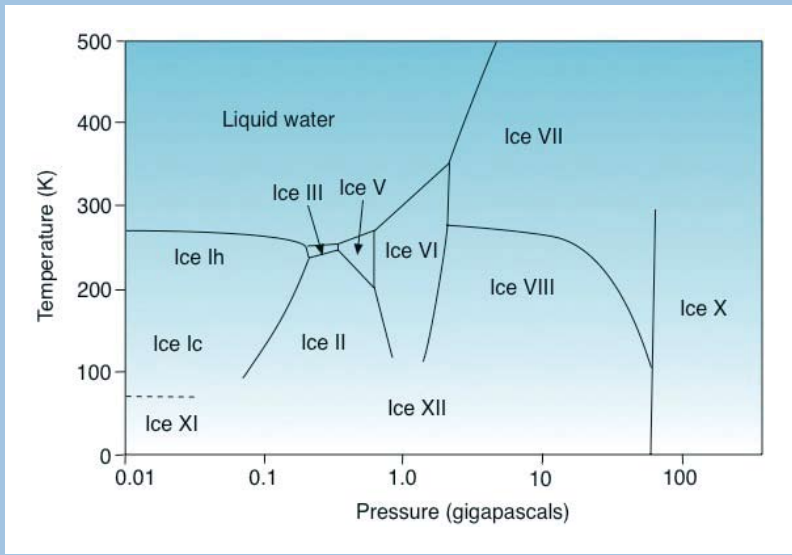
## Water oddities

The fact that ice has so many phases is just one of the peculiarities of water itself. It's odd that ice is less dense than water: most liquids get denser when they freeze. Water is actually densest at 4°C, whereas most liquids just get steadily denser as they cool. And there may in fact be two kinds of liquid water, although they exist only well below water's normal freezing point.

All these so-called anomalies stem from the same cause. Water molecules have the chemical formula $H_2O$, containing two hydrogen atoms linked to one oxygen atom in a bent shape (Figure 1a). And the hydrogen atoms on one molecule can form weak intermolecular chemical bonds, called hydrogen bonds, to the oxygen atoms of another. This means that water molecules may become bound together by temporary 'handclasps' that are continually breaking and reforming, as hydrogen bonds form and then break because of the jiggling influence of heat.

### Box 1 The many phases of water

When Kurt Vonnegut wrote about his fictional ice-nine, it was already known that ice has several phases, as shown in the diagram. The first new form of ice was discovered in 1900, and several were found subsequently by the American scientist Percy Bridgman at Harvard University, a pioneer in experiments at high pressure. No doubt this was why Vonnegut chose to call it ice-nine, for he was trained as an engineer and probably knew that ice-II, ice-III and so on had already been discovered.




*The phase diagram of some of the known forms of ice, showing where they are stable at different temperatures and pressures. 1 gigapascal is 10 000 times atmospheric pressure.*

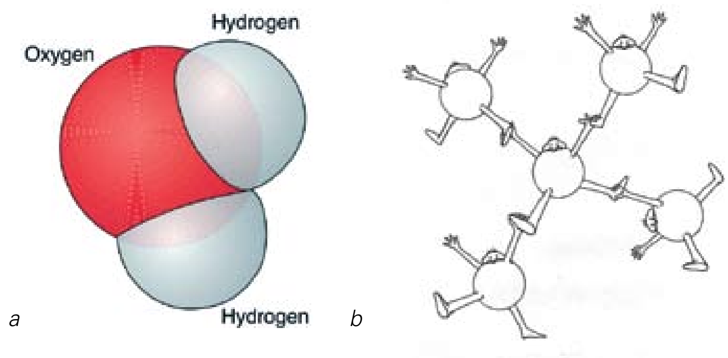
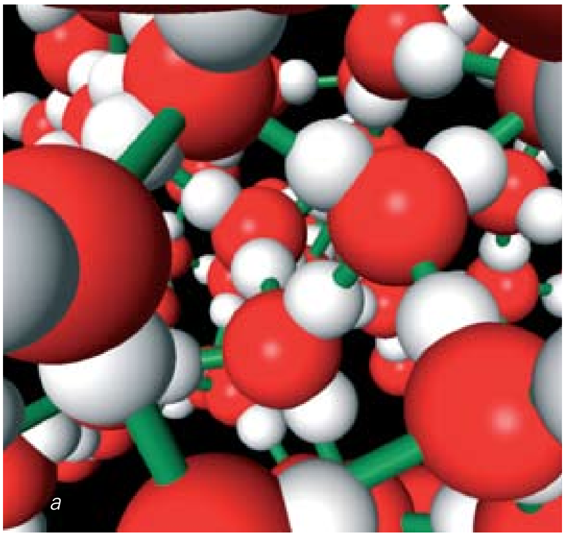



***Figure 1*** *a The structure of the $H_2O$ molecule.*
*b Each water molecule can form four hydrogen bonds to its neighbours, like hands grasping neighbours' feet in a perpetual dance.*

Each water molecule can form four hydrogen bonds: two via its hydrogen atoms, and two in which hydrogen from other molecules fasten onto the central oxygen atom. In effect, you could say that water has two hands to grasp other waters, and two feet that others can grasp (Figure 1b). The hydrogen bonds link water molecules into a gigantic network whose links are forever breaking up and rearranging. In liquid water this network is disorderly (Figure 2a), but in ice it has a more rigid shape in which $H_2O$ molecules are joined in hexagons (Figure 2b). This underlying hexagonal symmetry of ice explains why snowflakes are sixpointed (Figure 3). And it is because the hexagonal rings encircle a lot of empty space that ice is less dense than water.



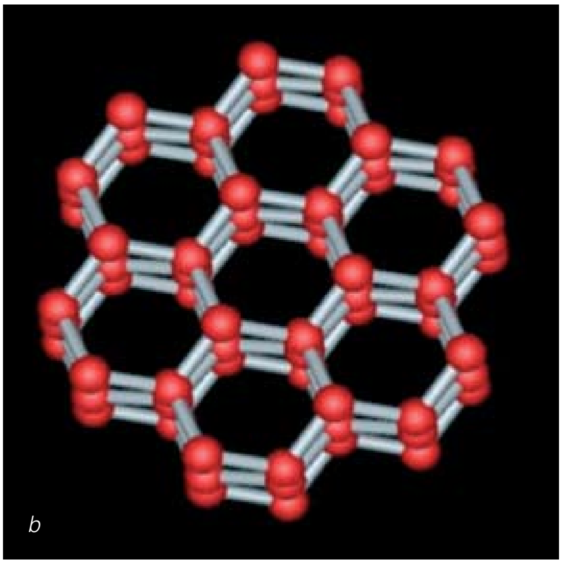




***Figure 2*** *a The disorderly hydrogen-bond network of liquid water. b In ice, hydrogen bonds link the molecules into orderly hexagonal rings.*

***Figure 3*** *The hexagonal symmetry of a snowflake*

As the Snowball Earth theory demonstrates, the behaviour of water has profound implications for the entire planet. It is only because of the unusual fact that solid water floats on liquid water, for example, that we have an Arctic ice cap (although maybe, if the planet continues to warm as fast as it is, not for much longer). Because a coating of ice on a lake insulates the water below, this helps prevent shallow lakes from freezing solid in winter and so ensures the survival of living things within them. And because water has an unusually large **heat capacity** – it takes a lot of energy to raise its temperature by a degree – warm ocean currents can redistribute vast amounts of energy around the globe, helping for example to keep the climate of northern Europe temperate. (For the same reason, however, kettles take a long time to boil.)

The delicate interplay between the molecular structure and the properties of water is perhaps most important of all in biology. Once scientists used to think of living cells as bags of biomolecules such as proteins and DNA that interact with each other in exquisite ways while simply being suspended in a liquid solvent of water. Now they have come to realise that these biomolecules actually fine-tune the water around them, using hydrogen bonds as handles to rearrange the molecules into new configurations that help the biomolecules themselves to come into contact and feel each other's presence. Proteins and nucleic acids seem to rebuild their own watery environment, you might say. Some line water molecules up in chains that can act as 'wires' for transporting hydrogen ions in catalytic processes (Figure 4). Others use water molecules as snap-on tools to help capture and transform their target molecules. It's the ability of water to shape and respond to molecules within it that makes life possible.

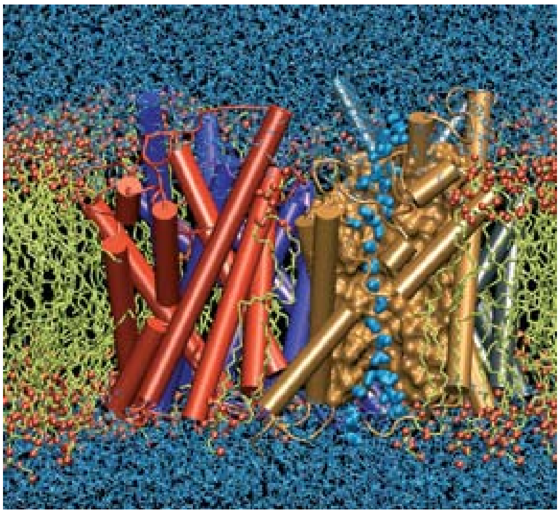


***Figure 4*** *A snapshot of water molecules (blue) around a protein called aquaporin, embedded in a cell membrane (yellow). Aquaporin controls the water coming in and out of cells, like a kind of molecular sluice gate. The water passes through a narrow channel in the protein, where the molecules get lined up in a chain, linked by hydrogen bonds.*

## Artificial snow

The cinema, television and advertising industries make great use of artificial snow. This is often a frozen mixture of water and paper or plastic. Look for the gallery at *www.snowbusiness.com*

*Blowing artificial snow … and outside Willy Wonka's chocolate factory*

## Odd ideas

But because liquid water remains still so hard to understand – its complicated hydrogen-bonded structure is hard to fully capture in computer models – and because it features so deeply in our stories and myths, it seems to have a limitless capacity to spawn strange and eccentric scientific ideas (see Box 2). One is that water possesses a 'memory', somehow retaining an imprint of molecules that have been dissolved in it so that it can mimic their behaviour when they are removed. This idea arose from experiments seeming to show that some solutions of biological molecules retain their biological activity when diluted until none of the molecules actually remained in the water. It's wrong, but is now often put forward as an 'explanation' for homeopathy. Many other spurious proposals have been made that water can act as an energy source, a kind of fuel.

Nils Volkmer/bigstockphoto

These claims, which generally rely on evidence that is barely detectable and hard to reproduce, are examples of what the American chemist Irving Langmuir called **pathological science**. And in a weird coincidence, Langmuir is allegedly the model for Vonnegut's Felix Hoenikker, the discoverer of ice-nine. It's said that Langmuir once tried to persuade H. G. Wells to take up an idea for a science-fiction story about a new form of ice, when Wells visited Langmuir's lab at General Electric in Schenectady, New York. Wells wasn't convinced. But also present at that meeting was the company's publicity officer, one Bernard Vonnegut, who later passed on the idea to his brother...

## Box 2 Pathological science: the polywater fiasco

Vonnegut's ice-nine catastrophe of the oceans was echoed just a few years after his book was published when Russian scientists led by Boris Deryagin in Moscow claimed to find a new form of water. This, they said, forms only in very narrow glass capillaries, and it is extremely sluggish, rather like Vaseline. Other scientists speculated that it was a kind of polymer form of water in which the molecules had somehow become linked together via stronger bonds than ordinary hydrogen bonds, and it became known as polywater. When word reached the West in the late 1960s, a frenzy of research on polywater brokea out, with various other groups claiming to have made some.

In 1969, one researcher suggested that polywater might be 'the most dangerous material on Earth', because it might do just what Vonnegut's sliver of ice-nine had done: seed a transformation of the oceans, in this case turning them to goo. Several more influential scientists quickly ridiculed this idea. And by the start of the 1970s, it started to become clear that polywater didn't exist at all – it was probably just some gunk made from impurities in the water used by the Russian scientists, such as silicate ions dissolved from the glass of the capillary tubes. Before long, polywater had become a massive embarrassment to the community of scientists who studied water, but it was by no means the last outbreak of 'pathological' water science.

*Philip Ball is an editor of the top science journal* Nature. *He is author of* $H_2O$: A Biography of Water *(Phoenix, 2000).*

## Look here!

There's a huge amount of information about water on the web site maintained by Martin Chaplin of South Bank University:
*http://www.lsbu.ac.uk/water/*

Andrei Merkulov/bigstockphoto

Will Marshall

# Becoming a Chartered Engineer

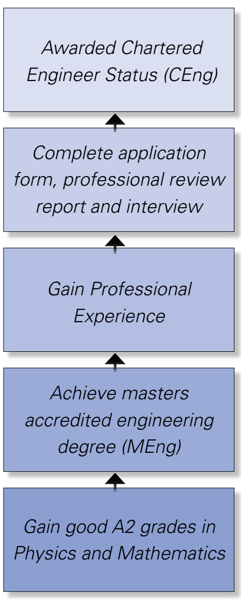
*A chartered chemical engineer at work*

*Thinking of becoming and engineer? For a professional engineer, gaining chartered status is a key milestone. Having recently achieved this himself, Will Marshall is in a good position to explain what this means.*

**Will Marshall is a fire services engineer. He ensures that engineering projects are designed to minimise the risk of fire and the hazard to life and property.**

Firstly let me explain what a Chartered Engineer is. Lots of people call themselves engineers, ranging from the person that comes to fix your boiler, to someone that designs bridges, to someone like myself who designs fire strategies and fire engineering solutions. These people are correct to call themselves engineers of a sort, but the level of skills and experience can vary greatly among them.

Education and practical experience are both taken into consideration when an engineer applies for chartered status. A Chartered Engineer is an engineer who has reached a high level of competency and commitment to professionalism in their particular branch of engineering. Standards vary to an extent between countries. In the UK, the Engineering Council set the skills and competencies required to become a Chartered Engineer.




*Chartered engineer - career structure*

Lisa F. Young/bigstockphoto

*Engineering students often work with professionals on real projects.*

## Chartership benefits

The benefits of becoming chartered are many and will vary for each individual and each specialism within the broad field of engineering. They will however, generally, increase your promotional prospects (I was promoted when I achieved chartership), your earning power, respect from people both within and outside of the engineering industry, and many more. With these benefits come a level of responsibility to the engineering profession and yourself with rules and regulations which must be followed. Clearly there is a benefit for all professional engineers aspiring to and working towards chartered status. And once you have achieved chartered status, you can put the letters CEng after your name.

The main elements of the chartership process are shown in the flow diagram (left). The actual application is made through a professional engineering institute such as the Institute of Fire Engineers.

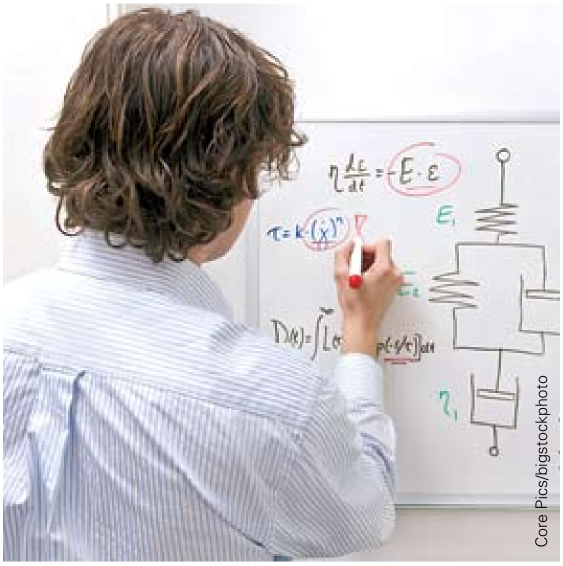
## Education

The educational phase of the application is probably the most structured of the three stages to complete. The trick is to ensure that you get yourself a place on an engineering course that is accredited by the Engineering Council. This is something that universities will usually highlight on course prospectuses but you can check on the Engineering Council's website. To gain entry to an accredited engineering degree course you will normally need to have A2 level Maths and Physics. A masters level degree or equivalent is required to meet the educational requirements for the Chartered Engineer application. It is necessary to achieve higher A2 grades to enter the masters degree (MEng) rather than the bachelors degree (BEng). In the case of Brunel University, where I studied, it is possible to gain entry to the BEng initially and transfer to the MEng if a high enough grade is achieved during the first two years of the degree, which I did.

*Hats off! Graduation day for the engineers*

## Professional experience

Once you have achieved your educational background to engineering now is the time to put all that training into practice. But its not just engineering skills that are needed to become a Chartered Engineer. Skills are also needed in management of technical work and people, business, and professional judgement. These skills will not be learnt or even be needed at an early stage of your career and several years experience will be needed. I became chartered after four an a half years of experience but it can take more than this.




*An engineer must demonstrate good communications skills.*

The way you gain your experience and competencies will very by individual, company and institute so I won't even try to go into this in this article. There are many advantages and disadvantages of each route so be sure to research thoroughly and pick the right one for you.

I have worked in both England and Scotland where the fire codes vary significantly between countries. Working in these two different environments was very beneficial and helped round me as an engineer. I would wholeheartedly suggest any opportunity that you are presented with to work in a different environment you embrace as you will gain experience much more quickly and over a wider skill base.

## Application and interview

The application and interview process does not require you to develop any further skills, they simply require you to demonstrate those that you have learnt. I found that the process of preparing the application identified to me a number of skills which I didn't realise that I had. So simply by completing the application I have improved further as an engineer by becoming more aware of my abilities.

The details of the application process vary by institute but normally consist of preparing a professional review report, filling in an application form and attending an interview.


*A telecommunications engineer – he belongs to the Institution of Engineering and Technology.*

## The long road

For most professional engineers, chartered status is likely to come when they are in their late twenties, perhaps 10 years after leaving school. It takes that long to gain a higher degree and to have the necessary experience. This may seem an awful long way off to you, but by planning now you will certainly benefit later.

***Will Marshall** MEng CEng MIFireE is a fire services engineer based in Edinburgh.*

*Will Marshall at his desk*

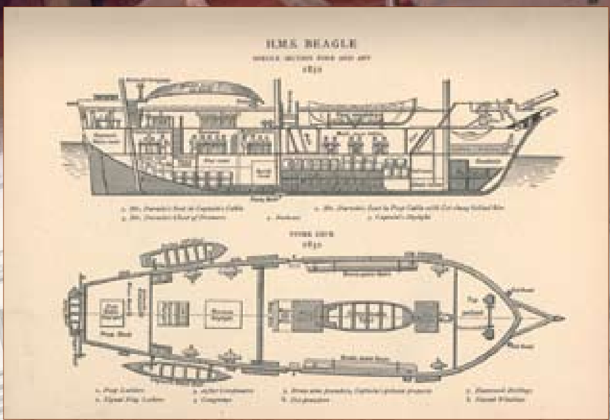
**Professional bodies**

Many branches of science and engineering are governed by a professional body with a royal charter. Examples are the Institute of Mechanical Engineers (IMechE) and the Royal Society of Chemistry (RSC). Professionals working in these areas can apply to become members and, later, fellows of these bodies, indicating their professional status. Some of your teachers will belong to professional bodies.

# Beagle voyage

*Charles Darwin spent almost five years on board HMS Beagle as it sailed around the world. The purpose of the voyage was to map navigation channels around the coast of South America. Darwin was the ship's naturalist and companion to the captain.*

The young Darwin in his cabin, as recreated at Down House



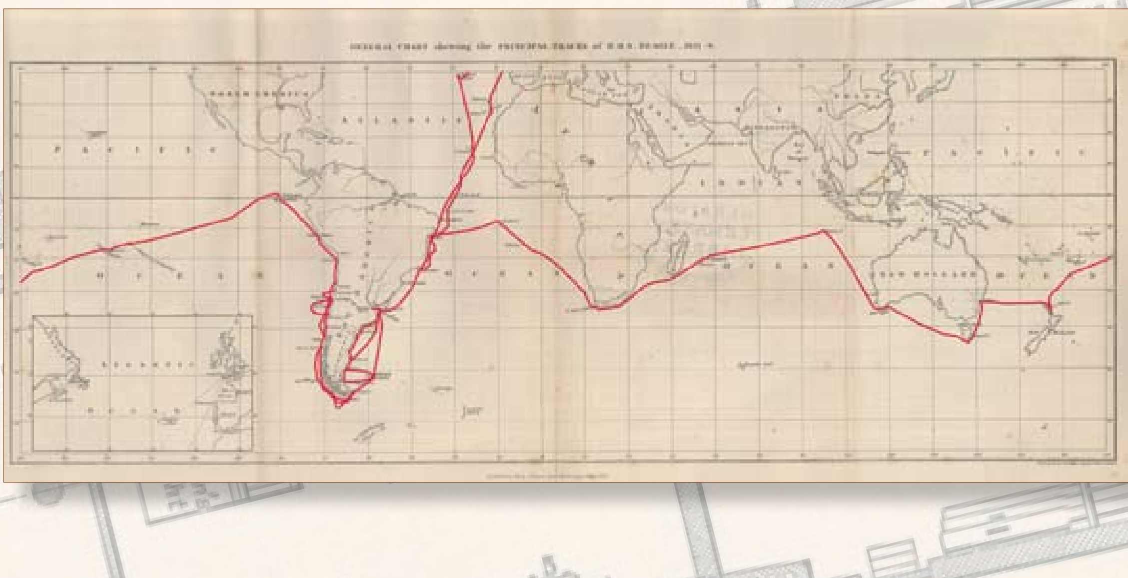

The Beagle was just 30 m in length.

Robert Fitzroy, captain of HMS Beagle

A heavy-billed finch from the Galapagos, a key clue to the idea of natural selection.

Darwin collected fossils – this is the skull of an extinct ground sloth from Argentina.

HMS Beagle in the Magellan Straits, observed by native people of Tierra del Fuego.



Darwin encountered many native people – these are Fuegians.