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Opening the door to Maxwell's Demons

Edinburgh-based scientists have fathomed one of physics' longest running thought conundrums by harnessing nanotechnology, says IAN JOHNSTON

IT HINTED at the possibility of a perpetual motion machine, tantalising the finest minds of several generations by the apparent contradiction of the laws of physics.

James Clerk Maxwell – the Victorian physicist ranked alongside Einstein and Newton – was no doubt tormented by the atom-sized machine he imagined some 140 years ago that seemed capable of producing energy out of thin air, so it is apt that his thought experiment is known as "Maxwell's Demon".

A theoretical solution to explain why it would not actually do so came only with the birth of computing and the realisation that processing information – the apparently abstract concept of thought – actually costs energy, even the act of "forgetting" or deleting it.

This week came an announcement that would have no doubt delighted Maxwell: a team of scientists from Edinburgh, where he was born, have managed to build a molecular machine which works in the same way as his thought experiment, using the new science of nanotechnology.

The device, detailed in a paper in the *Nature* journal, conforms to the laws of physics, creating no more energy than is put in.

But it represents a new kind of nano-motor which can be powered simply by a beam of light, which could lead to the ability to move objects around using a laser pointer. Maxwell's thought experiment is disarmingly simple:

- First, imagine a box filled with gas, which would contain molecules buzzing about with energies both above and below the average.
- Put in a panel that divides the box into two halves, but has a molecule-sized door which can let molecules pass through or block them.
- Now imagine a being or "demon" watching the molecules as they approach and opening the door to allow high-energy particles, which would be hotter, through into one side but blocking the lower-energy particles.

Gradually, one box would fill with more high-energy particles, becoming hotter than the neighbouring compartment, and this temperature gradient could be used to create energy.

Maxwell knew that creating energy out of nothing was impossible, but was unable to provide an explanation as to why his machine, if it could be built, would not actually work.

It was a problem that troubled physicists for decades. The solution emerged gradually between the 1920s and the 1980s, amid the birth of computers.

The act of simply opening the door would not cost the energy equal to that produced by the device, so the answer had to lie within the demon operating the door.

The demon would have to assess whether the molecule was hot or cold and also analyse its location and movement in order to make a decision about whether to open or close the door. Processing this information would have an energy cost. Gradually, this mass of information would build up to the point that the demon ran out of storage space, forcing it to discard or "forget" some. Computing science has shown that the act of deleting one "bit" of information also costs energy.

Perhaps helped by the snappy name given by Lord Kelvin, the thought experiment has remained a persistent object of interest for those outside the world of theoretical physics.

The American historian Henry Adams, who died in 1918, tried to adapt it to a pseudo-scientific theory of history, but was criticised for failing to understand what Maxwell was actually talking about.

Maxwell's Demon is the name of a progressive rock band in New York interested in complex rhythms and "non-tonal harmony" and a 1968 film by experimental film-maker Hollis Frampton.

The demon also appears in the Max Payne computer game and a Thomas Pynchon novel, *The Crying of Lot 49*.

But the Edinburgh University researchers' work brings the idea back to its scientific origins. It is based on another version of the Demon in which molecules are sim-

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ply allowed to move from one compartment to another but not back again, creating a pressure gradient that can be turned into energy.

Professor David Leigh said: "We have used Maxwell's thought experiment as the inspiration to design a mechanism for a working nano machine.

"It works exactly the same way as the pressure demon. We've created two compartments with a door between them. When a molecule in the left-hand compartment approaches, the door opens and the molecule is let through; when something is in the right-hand compartment, it is not. Something by the door 'looks' to see if there's something in the right-hand compartment, and if there is, it opens the door.

"Maxwell reasoned that if such a system could ever be made, it would need energy to work. Without energy, it might appear that the perpetual motion of the molecules could power other devices in the same way as a windmill, but Maxwell reasoned that this would go against the second law of thermodynamics.

"As he predicted, the machine does need energy, and in our experiment it is powered by light. While light has previously been used to energise tiny particles directly, this is the first time that a system has been devised to trap molecules as they move in a certain direction under their natural motion."

Applications of the nanotechnology machine could include trapping molecules to generate a force in front of a solid object using a laser pen. By shining the pen in the direction you want the object to move, the force of the molecules could be harnessed to push the object along.

Prof Leigh said it was a testament to Maxwell's greatness that his ideas were still relevant to science today.

"I think Maxwell was undoubtedly one of the three great geniuses, along with Einstein and Newton. Maxwell's Demon has had an incredible impact on science, computing, the theory of information and lots of things. The theory of information is based on the very strange relationship between information and energy," he said.

"It's a fantastic, amazing story that is still relevant today. Molecular machines are going to change the world in the coming years. At the moment, we don't use molecular machines to do anything, but nature uses molecular machines to do everything from photosynthesis, the way your muscles move and the brain works.

"Nature hasn't selected that solution for no reason over billions of years… it's come up with that because you can do amazing things."

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MORE INFO

Anyone interested in finding out how much energy the Demon would have to expend separating hot from cold molecules can have a go at this online computer game: http://absolutist.com/online/demon/

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As James Clerk Maxwell, left, predicted, the molecular machine does require energy. The Edinburgh experiment is powered by light
Picture: Alamy