never decrease; and that it is impossible to cool an object to absolute zero. But thermodynamics is paradoxical. The second law, which also puts limits on how efficiently heat can be converted into work — as happens in a steam engine — is particularly controversial.

The law says that the production of disorder is irreversible. But some physicists argue that at the microscopic level, this seems to conflict with the laws of mechanics — be they those of Newton or of quantum physics. Mechanical laws, say these researchers, prescribe that all processes can be reversed.

Researchers have come up with different approaches to solving this conundrum, but none has satisfied everyone. "This has always been a bit of a dirty business," says Christian Gogolin, a physicist at the Institute of Photonic Sciences in Castelldefels, Spain.

Gogolin's work involves taking statistical mechanics, in which quantities such as temperature or heat are averaged properties of systems made of many particles, and developing a quantum version of it. Some physicists maintain that this statistical-mechanics approach suggests that quantities such as entropy or heat depend on the information an observer possesses. In particular, an all-seeing, 'godlike' being could know the positions and motions of each particle and calculate their evolution, and this level of order would be in the eye of the beholder.

This approach has been revived in recent years, as many physicists have come to regard information as something quantifiable, and with physical significance.

Statistical mechanics is even murkier in systems made of relatively few particles and governed by quantum laws. For example, if the tendency towards disorder is a purely statistical phenomenon, it might in principle not apply to a single molecule. Yet in the past decade, theorists have suggested that quantum systems tend to reach and maintain a state of equilibrium — or maximum disorder — even when they have just a handful of components. Experiments confirmed this with small numbers of atoms trapped by laser light in a vacuum[1].

"This has always been a bit of a dirty business."

And in a 2011 theory paper in *Nature*, Vedral and his collaborators showed that quantum correlations — the ability of particles to share an 'entangled' quantum state when far apart — can be harnessed to produce mechanical work[2].

More recently, physicists have made progress with the third law. In a paper published on 14 March in *Nature Communications*[3], Lluis Masanes and Jonathan Oppenheim at University College London showed that the laws of quantum mechanics limit how fast heat can be extracted from an object, and that reaching absolute zero would take an infinite amount of time. Their work seems to confirm that the third law emerges from quantum mechanics.

A more radical proposal, by Oxford theoretical physicists Chiara Marletto and David Deutsch, suggests a set of principles that all physics theories have to satisfy, a sort of a 'theory of everything' from which laws such as quantum mechanics should follow. And in a 2016 preprint[4], Marletto sketched out how this set of meta-laws leads to a redefiniton of thermodynamic concepts in terms of rules that physical transformations have to obey.

Whatever the outcome of these debates, they may have implications for future technologies. Physicists have made 'quantum heat engines' — that can turn heat into work at the quantum level[5]. Applications such as quantum computing are moving from the theoretical to the real world, so understanding thermodynamics on a tiny scale could be crucial. "You need to design algorithms that are not just faster," says Renner, "but also thermodynamically optimized." ■

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FUNDING

Canada budget falls flat

Emphasis on innovation overshadowed by funding freeze for key research councils.

BY NICOLA JONES

The budget that Canadian Prime Minister Justin Trudeau's government released on 22 March lives up to his promises to emphasize innovation, and to encourage links between industry and academia. But it also presents scientists with a depressing, and unexpected, freeze on the main funding streams for basic research.

"This budget is really focused on innovation and skills," science minister Kirsty Duncan told *Nature*. "Last year we had over $2 billion for science, and this year over a billion for innovation. This is a government that respects research and science."

The plan promises to establish Innovation Canada, a new central platform to co-ordinate and simplify support for Canadian entrepreneurs. And there will be Can$950 million (US$710 million) available over five years to support "superclusters": areas dense with companies and academics, similar to California's Silicon Valley, that are designed to push forwards innovative industries such as clean technology.

But critics note that much of this money isn't new; the Can$950 million, for example, is reallocated from pots set aside in last year's budget. And there is little in this year's announcement for basic research. In particular, no mention is made of annual budgets for Canada's three major research councils, which deal with the natural, health and social sciences. This means that they will have no budget increase at all this year.

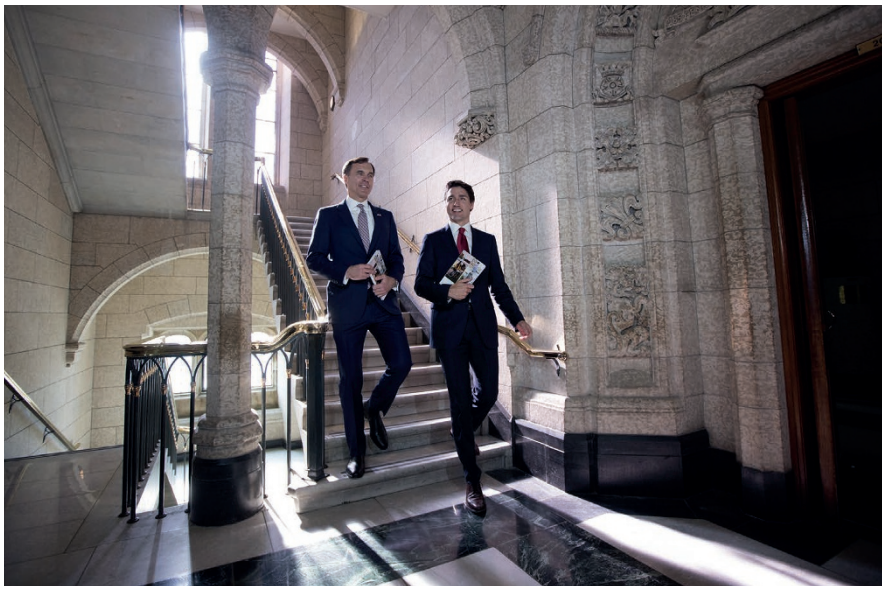
"The tri-councils get something every year for cost of inflation. I can't remember when they got nothing," says James Woodgett, a biomedical researcher and director of research at the Lunenfeld-Tanenbaum Research Institute in Toronto. "It sends the wrong message, especially with what's going on in the US."

The flat funding for the three research councils is odd given the emphasis that Trudeau's middle-left Liberal government has placed on science. The prime minister's first budget, released last year, injected badly needed cash into those granting agencies, more than doubling the meagre annual increases they had received under the former Conservative government.

MISSING PIECES

Trudeau's government is probably sticking to the status quo while it waits for the results of the Fundamental Science Review, an independent assessment of the country's systems for supporting science, says Paul Davidson, president of the Ottawa-based advocacy group Universities Canada. That analysis will be released in the coming months, the budget notes. "In the interim, the granting councils can continue to do their work at current levels," Davidson says.

The budget does set aside Can$2 million to fund the post of chief government science adviser. The decision to create that post, which will provide independent scientific advice to ministers, was one of the Liberal party's main



DAVID KAWAI/BLOOMBERG/GETTY

The second budget from Canadian Prime Minister Justin Trudeau (right) is a mixed bag for scientists.

campaign promises — and a big hit in the science community. So far, the government has moved slowly to fill the position. A search that began in December will produce the first adviser later this spring — about a year and a half after the Liberals took power — Duncan says. Two million dollars is "about right" for the office, says Kathleen Walsh, executive director of the non-profit science-advocacy group Evidence for Democracy in Ottawa.

A few other budget points also bring good news. There is Can$80 million to replace the ageing Sidney Centre for Plant Health, which was rescued from closure under the Conservatives in 2012. Another Can$125 million will fund a Pan-Canadian Artificial Intelligence Strategy, to bolster the country's lead in computing fields such as deep learning. The budget also includes money for training programmes, including Can$50 million to teach children computer coding and Can$221 million to help university graduates to find jobs.

TRUMPING THE UNITED STATES

A new set of 25 'Canada 150' research chairs has been established to mark the country's 150th birthday. Although this comes from an established pool of money, the positions will help to attract leading researchers to Canada from abroad, says Davidson. "Those chairs are an important tool when you're looking at what's happening post-Brexit and post-Trump," he says, referring to unease over immigration policies and funding in the United Kingdom and the United States. "The number of hits on our job site has doubled since November."

And whereas US President Donald Trump has proposed cutting support for climate-change research, Trudeau's budget introduces several climate programmes. It includes Can$73.5 million for a Canadian Centre for Climate Services to improve access to climate science, and Can$83.8 million over five years to integrate traditional knowledge of climate change — including that of the First Nations — and enhance the resilience of northern communities.

The lack of major increases in funding comes in the face of challenging finances. The Liberals campaigned on a promise to keep deficits below Can$10 billion a year, but their first budget pushed it to more than Can$25 billion. This year's budget stretches the deficit to Can$28 billion.

"If I'm being generous, I'd say we weren't expecting a lot [for science], but we didn't get anything," says Woodgett. "I'm pretty disappointed." ■

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DATA SHARING

Gates to launch open-access publishing site

Health foundation joins push for greater transparency.

BY DECLAN BUTLER

One of the world's wealthiest charities, the Bill & Melinda Gates Foundation in Seattle, Washington, is set to launch its own open-access publishing venture later this year. The initiative, Gates Open Research, was announced on 23 March and will be modelled on a service begun last year by the London-based biomedical charity, the Wellcome Trust. Both efforts are intended to accelerate the publication of articles and data from research funded by the charity.

Along similar lines, the European Commission is considering its own open-access publishing platform for outputs from its €80-billion (US$86-billion) Horizon 2020 research programme. At a conference on open science in Berlin on 21 March, a commission representative suggested that the service might launch this year, says Sabina Leonelli, a philosopher at the University of Exeter, UK, who attended the meeting. A spokesperson said that the commission was looking at the models used by the Wellcome Trust and Gates Foundation, and had asked a panel called the Open Science Policy Platform (of which Leonelli is a member) to provide an opinion on the idea.

Like the Wellcome Trust, the Gates Foundation has contracted management of its publishing service to *F1000Research*, an open-access platform that rapidly publishes papers and data sets after an initial sanity check by its in-house editors. Papers are peer-reviewed after publication, and the reviews and the names of their authors are published alongside the studies.

The foundation will have no editorial oversight of Gates Open Research, says spokesperson Bryan Callahan. It will also fully cover all article-processing charges (APCs) — US$150 for articles of up to 1,000 words, $500 for 1,000–2,500 words and $1,000 for articles exceeding 2,500 words.

The Gates Foundation has one of the most stringent open-access policies of any research funder. Researchers must make their papers and data open access upon publication, and allow unrestricted reuse. "We believe that published research resulting from our funding should be promptly and broadly disseminated," says Callahan. "Our research saves lives." ■