NEWS AND ANALYSIS

Pregnant female PhD students face significant challenges

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News & Analysis

Critical research hit by COVID-19

Major labs have shut their doors in response to the worldwide lockdown, but a few remain open and in some cases are carrying out critical work related to the COVID-19 pandemic, as **Peter Gwynne** and **Michael Banks** report

Physicists continue to be affected by the global lockdown arising from COVID-19 – the disease caused by the SARS-CoV-2 virus that is sweeping the planet. Government laboratories around the world have either shut down or required employees to work from home while closing to visitors. The schedules of forthcoming space missions have been put at risk. Administrators of major telescopes have restricted or postponed critical observations. Postgrads and postdocs, meanwhile, have seen their career paths put on hold as universities shut their doors.

In the US, national laboratories overseen by the Department of Energy (DOE) have suffered significant disruption. That occurred initially as a result of geography, with the virus having made its first deadly impact in the state of Washington. Most staff at the DOE's Pacific Northwest National Laboratory in Richland, for example, have been working at home since early March. California's Bay Area also emerged as an early hotspot.

A directive from California governor Gavin Newsome, which prohibited inessential travel and meetings, led to the effective shutdown of the SLAC, Berkeley and Lawrence Livermore national laboratories, as well as of the local branch of Sandia National Laboratory, with most of their employees now working remotely at home. There have been exceptions, however. As *Physics World* went to press, the Berkeley Lab was in a "safe and stable standby" status, with some critical work occurring on-site. The lab's Advanced Light Source operating a limited number of beamlines for three days a week for users developing therapeutics to help combat the SARS-CoV-2 virus.

Other DOE labs have also restricted visitors, operated largely off-site or closed down as the virus created fresh hotspots. In New Jersey the Princeton Plasma Physics Laboratory shut down on 13 March, requiring all its employees to work at home. A week later, Brookhaven National Laboratory responded to New York governor Andrew Cuomo's order that employees in "non-essential" jobs should stay at home. A subsequent order by Illinois governor J B Pritzker also forced the Argonne and Fermilab facilities to restrict their operations. The Oak Ridge National Laboratory in Tennessee and the Idaho National Laboratory closed to visitors, researchers and the general public too.

ITER

Keep calm and carry on
Despite the impact of COVID-19 on physics around the world, construction at the ITER experimental fusion reactor in France is still ongoing, albeit with limited personnel.

'Heroes' work'

NASA has been similarly affected, with greater impact on specific missions. On 19 March NASA administrator Jim Bridenstine announced plans to put all the agency's centres under "stage 3 status", which requires all but "mission essential" staff to work remotely. "We are going to take care of our people," Bridenstine said. "That's our first priority." An immediate result of NASA's announcement was the temporary closures of the Michoud Assembly Facility in New Orleans and the nearby Stennis Space Center in Mississippi when the number of COVID-19 cases rose in the area. A result of the closures, Bridenstine noted, would be "temporary suspension of production of the Space Launch System and Orion Hardware" – key components of the agency's plan to land astronauts on the Moon in 2024. Analysts had already questioned the viability of that schedule under normal conditions, but it now seems even more doubtful.

A more immediate mission – Mars 2020 – remains on schedule, however. The $2.5bn project, which includes the newly named Perseverance rover, has a 20-day launch window that starts on 17 July. Failure to meet that window would delay the flight by two years. The mission has "the very highest priority", Lori Glazer, head of NASA's planetary science division, told a virtual meeting. "We're going to ensure that we meet that launch window in July." The project's engineers are doing "heroes' work" in maintaining that schedule, added NASA's science head Thomas Zurbuchen.

The schedule of another prestige project, the James Webb Space Telescope (JWST), is less certain. California's state-wide lockdown has affected Northrop Grumman Aerospace Systems in Redondo Beach, which had been carrying out shaking tests on the $8.8bn observatory. A successor of the Hubble Space Telescope, JWST has already suffered numerous delays and is unlikely to meet its current launch date of March 2021.

Several observatories belonging to the Event Horizon Telescope have also closed down owing to the coronavirus, with the organization having cancelled its observing campaign planned to take place in March and April. "We will have to wait for March 2021 to try again," the organization said in a statement. Elsewhere in the world of astronomy, the Atacama Large Millimetre/submillimetre Array in Chile has suspended operations, as has the Association of Universities for Research in Astronomy, which has stopped observations at several of the telescopes it oversees and halted construction of the Vera C Rubin Observatory in Chile.

Meanwhile, the Laser Interferometer and Gravitational-wave Observatory sites in Hanford, Washington and Livingston, Louisiana, suspended observations on 27 March as did the Virgo detector in Italy. However, operations at the Kamioka Gravitational Wave Detector in northern Japan are still ongoing.

Moving online

The need for social distancing has impacted events organized by scientific societies too. The American Physical Society, which called off its March meeting at short notice (see April pp10–11), also cancelled its April meeting, although some sessions were held online. The American Astronomical Society has converted its early June meeting to a fully virtual event.

Academic institutions face their own coronavirus issues. Many research universities have moved to virtual operation. Those decisions have put particular pressure on postgraduate students who need to be on-site to perform their research. Some institutions, such as Brown University and the University of Alabama at Birmingham, have frozen hiring. In late March, a group of four organizations representing US universities and medical colleges called on Congress to increase spending on research by government agencies.

The $2 trillion rescue package that President Donald Trump signed on 27 March included some relief to US institutions. It grants $100m to DOE labs, $75m for National Science Foundation grants, $66m for programmes of the National Institute of Standards and Technology as well as a fund worth $14bn for universities. Observers suggest that those amounts, while welcome, are too small. But the likelihood that Congress will pass another rescue package gives the US scientific community some hope of extra support.

> A few major projects are still continuing to some degree – albeit with limited personnel

European impact

COVID-19 has also forced most labs in Europe to close their doors. The CERN particle-physics lab near Geneva has reduced all activities on-site to those that are essential for the safety and security of the lab. CERN had been moving to the latter parts of a long shutdown in preparation for a major upgrade to the lab's Large Hadron Collider. That work has now been reduced, with officials at CERN working out how the impact will affect the timeline of the upgrade project, which was due to be complete in the mid-2020s. The CERN Council also announced in late March that it had postponed the release of the European strategy update that was due to be released this month.

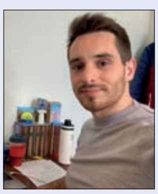
However, a few major projects are still continuing to some degree. Mission controllers at the European Space Agency's European Space Operations Centre in Darmstadt, Germany, tested instruments on the agency's Bepicolombo mission to Mercury as it completed a fly-by of Earth on 10 April – albeit with limited personnel. The ITER fusion experiment being built in Cadarache has cancelled all on-site visitors and onsite meetings, but is continuing with "critical responsibilities and functions". Indeed, the project is still managing to undertake some construction tasks and has taken delivery of magnet components that have arrived from member states. It does look likely, however, that the SARS-CoV-2 virus will put back the start of operations that are currently planned for 2025.

The European Spallation Source, currently under construction in Lund, Sweden, has also put in place measures for staff to work remotely as well as cancelling visits to the site. Yet work is still continuing, with workers having recently installed the water tanks that are used for the proton target. Other, existing neutron and X-ray synchrotrons facilities in Europe have closed though, including the Institut Laue–Langevin and the European Synchrotron Radiation Facility, both in Grenoble, France, as well as the ISIS neutron source in Oxfordshire, UK.

Some facilities remain open for scientists to carry out research on the SARS-CoV-2 virus. These include the Paul Scherrer Institute in Switzerland, the UK's Diamond Light Source and the MAX IV synchrotron in Sweden, which are all fast-tracking relevant proposals.

Physics in the pandemic

How has the COVID-19 pandemic affected the personal and professional lives of physicists around the world? Here are six stories -- you can find longer versions of each (and many others) online on the *Physics World* blog

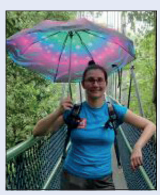


Sam Vennin is a biomechanical engineering research fellow at Guy's and St Thomas' Biomedical Research Centre and King's College London, UK

2 April

I have been working from home while trying to stay away from the news as much as possible. As for the hospital I work in, where Florence Nightingale established the first professional nursing school in the world, it probably looks more like a war zone now than a workplace. My work is highly interdisciplinary, ranging from designing new technologies to help clinicians assessing cardiovascular status, to gaining more fundamental understandings of hypertension, and a lot of it depends on collaborations with clinicians and doctors.

Since the beginning of the outbreak, all cardiovascular MRI scans in my hospital have been cancelled, putting on hold most of the clinical studies I am involved in. Similarly, I haven't heard from some clinical supervisors and collaborators, who I assume have been requisitioned or have volunteered to help. I am trying to finish the papers and software I was working on, hoping that they can add their parts and insights later. I also communicate with my engineering supervisor and am watching out for ways to help.

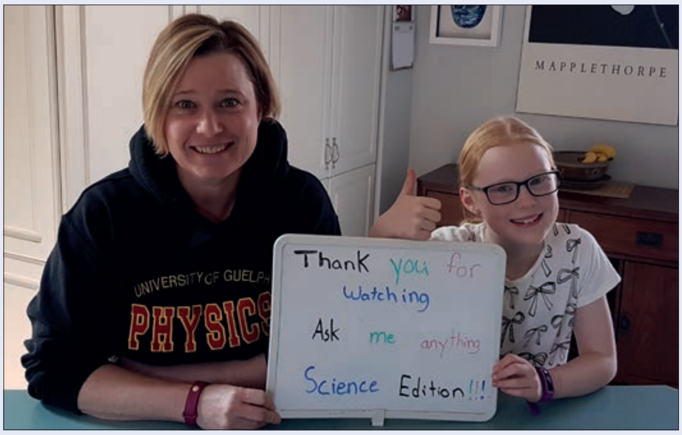


Ana Rakonjac is an experimental physicist at a quantum technology start-up in Singapore

23 March

The quarantine is taken very seriously in Singapore. The authorities will check in with you every day, and you can be fined, jailed and/or deported if you don't comply. This has severely limited community spread of the virus. The government quickly implemented measures to support people who are quarantined, such as ensuring that they get extra sick leave and don't lose their jobs if they can't work from home, plus there are some big stimulus packages planned. Additionally, COVID-19 tests and hospitalization are free for residents. We've had major supply chain problems. First, with China, where several orders got stuck in limbo – they were ready to ship, but there was no-one to send packages and no-one to deliver them.

Many local suppliers also heavily rely on China, so we were unable to use them. We turned to manufacturers in India, and things were going well until the second week of March, when they also started shutting down. We've been hurriedly trying to procure all we need for the next few months because although we expected more global shutdowns, I personally didn't expect it to happen so fast. Over just a few days, some European suppliers have gone from saying they expect no delays to suddenly shutting down their facilities. I think things will continue to be unreliable for months, since there is no way that two-week shutdowns will be enough to stem the spread of the pandemic. We will have to find some creative solutions.



Joanne O'Meara

Joanne O'Meara is a physicist at the University of Guelph in Canada

28 March
Brrrring! There goes the bell at the school across the street from our home, but it's unusually quiet. No line of big yellow school buses dropping off little ones; no stressed parents parking across the bottom of our driveway as their charges dash in the front door. Normally, I would be sitting at my desk at the University of Guelph by now, scrolling through the morning's e-mails and prioritizing my "to do" list for the day. Instead, I'm making sure that my nine-year-old is starting on her journal-writing assignment and my 14-year-old is finding reliable sources for her project on the forestry industry.

Welcome to my new role as university professor, housekeeper, cafeteria lady, elementary- and high-school teacher, principal, secretary and school-yard supervisor. I wasn't teaching this semester, so my main pivot to online has been to find creative ways to support my fourth-year physics students trying to finish their honours thesis projects. This semester is research leave for me, which means finalizing the second edition of our textbook and exploring new ways to connect with the community and support science education at all levels. The writing part – that's relatively easy to do at home, although I'm now in slightly more chaotic settings than I'm used to in my quiet little campus office.

Mike Follows is a physics teacher at King Edward's School, Birmingham, UK

6 April
During quieter moments in those last days at school before the shutdown, colleagues shared their anxiety about what was to come. It was like waiting for a tsunami that is sure to strike but without knowing how big the wave will be and how much damage it will wreak. Quite naturally, there was also some anxiety about being in such close proximity with other people, mainly students, who might be asymptomatic super-spreaders. Media reports suggest that people in the lowest age groups are as good as immune to the virus, which is perhaps why among our boys, the novelty of using hand sanitisers wore off within a day and they were fairly blasé about social distancing.

That final week at King Edward's also brought home to me just why the school is so successful. While it has more than its fair share of bright students and lots of talented teachers, it's more than just a school. It is a community, almost an extended family. In the face of COVID-19, the life of a teacher has become pretty surreal. Though it has made teaching and learning more difficult, I think we are happy that schools are shut for all except the children of key workers – if only so that it reduces the risk to our families and slows the spread of the virus more generally.

Bonnie Tsim

Bonnie Tsim is a PhD student in theoretical physics at the Graphene NOWNANO Centre for Doctoral Training at the University of Manchester, UK

27 March
The two days after my university closed its doors felt like a whirlwind. In-between packing up my life at university to work from home, I also attended and spoke at the Graphene Flagship's first ever virtual conference, Women in Graphene 2020, on 18–19 March. The conference was originally planned to be in Bologna, Italy, but shifted in early March to an online platform hosted by Virtway Events. Around 70 people from around the world attended the event and being virtual brought several advantages. It meant that those who may have otherwise struggled to make it to Italy were now able to attend. It allowed more people to ask in-depth questions or, perhaps, more personal questions that would be more difficult to ask at an actual event. It also allowed individuals in the Women in Graphene network to connect in a way never done before, such as continuing conversations and discussions after the event.

I have not yet quite found my new "normal". I am using the lockdown as downtime to prioritize and plan the remainder of my PhD. I am particularly thankful to those who are supporting me during these unpredictable times and I am making an extra effort to stay connected with friends, family and loved ones. It is more important than ever to keep connected to the physics community and to show each other kindness, support and care.

Tao Wang is an experimental physicist in the School of Materials Science and Engineering at Wuhan University of Technology in Wuhan, China

8 April
After 11 weeks of lockdown, people in Wuhan were allowed to leave the city from midnight on 8 April. The authorities are evaluating how to ensure public health and safety in these new circumstances, and when that is settled our students will be allowed to return to campus. I actually tidied up my office on that first day out, and I am waiting for our students to be back, which I am sure won't take long. With great efforts from people in every country, this extraordinary crisis will surely be overcome, and we will be back to "normal" life. But this new normality won't be the same as the one that existed before. It is going to change our society in ways we haven't fully anticipated.

I hope the changes are positive rather than negative. We should live in more healthy ways so that we can share this planet with other beings, and that will require everyone to think things over after the disruption is finished. I do see positive things in all nations across the globe: responsibility, selflessness, self-discipline, unity and resolve. I hope the rest of the world can see hope from my experience in Wuhan.

Physicists tackle ventilator shortage

Physicists in Europe have been working on designs to supply oxygen to COVID-19 patients, as **Edwin Cartlidge** reports

Members of the DarkSide experiment at the Gran Sasso National Laboratory in Italy have temporarily put their hunt for dark matter on hold in an attempt to stem the deadly tide of COVID-19. The 26 physicists from Europe and North America have designed a new, stripped-down mechanical ventilator that they hope can be mass-produced quickly and cheaply using off-the-shelf components. Liaising with medical professionals and calling on the expertise of fellow physicists, the group has produced a prototype and now hopes to see the technology employed in hospitals.

Many of the most seriously ill patients infected with COVID-19 develop pneumonia and need help breathing. That is done using mechanical ventilators, which pump oxygen into the lungs and then remove the carbon dioxide that is breathed out. This is a delicate process that involves regulating the pressure and/or volume of oxygen provided. It can be done either fully automatically on a sedated patient, or to support a patient's natural breathing.

The new ventilator design has been spearheaded by Cristiano Galbiati, a physicist at Princeton University in the US and the Gran Sasso lab, which is run by Italy's National Institute for Nuclear Physics (INFN). Galbiati says that he started working on the design after speaking to a friend on 19 March whose family had made a big donation to an intensive-care hospital that was being set up on the site of Milan's 2015 Expo to treat some of Italy's growing number of coronavirus patients. The friend told him that a consignment of ventilators that were supposed to be arriving from Germany had been cancelled. "That is when I realized we need to do something different," he says.

Galbiati quickly brought together colleagues from DarkSide, and using criteria published by the Medicines and Healthcare Products Regulatory Agency in the UK, which stipulate the essential features for any new design of ventilator, came up with a blueprint entitled Mechanical Ventilator Milano (MVM). This, he says, is inspired by a 1961 design from Roger Manley of Westminster Hospital in London, which was "basic but very reliable" – one of the main differences being that the new machine will use electrically driven pneumatic valves rather than mechanical switches.

iStock/Juanmonino

Clinical need
Patients infected with COVID-19 develop pneumonia and need assistance breathing, which is done using mechanical ventilators that pump oxygen into the lungs and then remove the carbon dioxide breathed out.

According to Galbiati, the MVM is compact and requires fewer parts than most ventilators on the market today. Its simplicity, he says, derives from the fact that it controls the pressure of oxygen in a patient's lungs using two fail-safe valves in the form of vent traps – nothing more than columns of water or oil with a specific depth. One trap positioned upstream from the patient ensures a certain maximum pressure during inhalation and another, downstream, dictates the minimum pressure following exhalation.

Unlike more sophisticated ventilators, the MVM would not be able to regulate the volume of oxygen into someone's lungs (as opposed to the pressure). Galbiati says he does not know how strictly necessary it is to be able to control both quantities but is nevertheless convinced that the new design would be a life-saver in Italy's heavily infected Lombardy region and beyond. "I can't say what is needed in most cases," he adds. "But what I can say is that there are patients who get no treatment. A mechanical ventilator that only has only pressure control will still be very valuable."

> The biggest remaining question is whether industry can produce the machine quickly enough to really limit the damage done by the virus

Laboratory tests

On 20 March Galbiati and colleagues carried out a first set of tests in a laboratory near the hard-hit city of Bergamo using some of the components of the MVM and a standardized test lung made from a silicone bag. They published a paper outlining their design and asked scientists and medics for feedback in order to "speed the process of review, improvement and possible implementation" (arXiv:2003.10405).

Galbiati says that developing the machine itself is not that difficult – a big technical challenge, he says, is producing the software that runs the device. "We have shifted the complexity to the controller and design software," he explains. "This is something that particle physicists excel at. But if we want to do it quickly, we need the collaboration of the best programmers from the strongest particle-physics labs."

Heading up the effort on the other side of the Atlantic is Art McDonald of Queen's University in Canada, who shared the 2015 Nobel Prize for Physics for the discovery of neutrino oscillations. McDonald says that he has been "mobilizing resources" from several Canadian particle and nuclear laboratories, including electronics expertise at TRIUMF, and mechanical engineering skills from Chalk River Laboratories and SNOLAB. Together with Galbiati he has also been drumming up support from Fermilab in the US and CERN in Switzerland.

McDonald says that he has had "excellent feedback" on the MVM from medical experts, including those in a group at McGill University in Quebec who are overseeing ventilators in Canada. Although, as *Physics World* went to press, Italy had not yet given formal regulatory approval for the design, he says that informally authorities have sent encouraging signals. Indeed, Galbiati says that they have granted special permits to re-open factories for the production of necessary items. McDonald also hopes that approval will be soon be given in Canada, having spoken to "authorities at the highest level" there.

The biggest remaining question, McDonald says, is whether industry can produce the machine quickly enough to really limit the damage done by the virus in Italy and elsewhere. "I don't know the answer to that yet," he says. "But we have a lot of very highly motivated individuals working on this."

From particles to ventilators

Physicists at the CERN particle-physics lab near Geneva have also been using their skills to design ventilators. Led by researchers from the LHCb collaboration they have designed a streamlined ventilator dubbed HEV (arXiv:2004.00534). The team realized that the systems used to regulate gas flows for particle-physics detectors could be employed in a novel ventilator. The HEV design could be used for patients with milder symptoms, so freeing up high-end machines for the most intensive cases.

CERN researchers built prototype in late March, with the pressure regulators, valves and pressure sensors being refined as *Physics World* went to press. The group was planning to then work with clinicians and international organizations to test the prototype in hospitals. Even if it comes too late to be used in Europe, HEV might prove handy in developing countries given that it can be operated with batteries, solar panels or emergency power generators. CERN has also been using its workshop and 3D-printing capabilities to produce protective equipment such as masks and Perspex barriers. "We want to deploy our resources and competences to contribute to the fight against the COVID-19 pandemic," says CERN director-general Fabiola Gianotti.

Analysis: Can physicists help solve the ventilator shortage?

As the novel coronavirus makes its relentless way across the globe, hospitals are still facing shortages of ventilators and other key equipment and supplies. It is only natural that physicists want to apply their technical skills to creating new ventilator designs that can be quickly manufactured. And it is not just physicists; engineers at companies that supply a wide range of products from vacuum cleaners to nuclear technologies have joined the effort.

However, these projects face huge challenges. In some places ventilators are needed right now, yet new devices must go through stringent testing to be approved for use. Also, will it be possible to train already busy intensive-care staff to use the devices and would they have confidence in the new technologies?

Regardless of whether these new ventilators are used on COVID-19 patients, scientists and engineers should be lauded for their efforts. And as often happens in science, there could be spin-off applications of the new ventilators such as use in developing countries where simple and accessible medical equipment is needed.

Hamish Johnston

Careers

Women's scientific impact hit by shorter careers

A large study of historic publishing data has found that men and women publish scientific papers at comparable annual rates and attract equivalent career-wise citations. Although male scientists tend to have more productive and impactful careers than their female colleagues, the bibliometric analysis has found that much of the gender variation is due to different career lengths and dropout rates (*Proc. Natl Acad. Sci.* 117 4609).

iStock/mocoo

Impact agenda A study has found that men and women publish scientific papers at comparable annual rates, but male scientists seem to be more productive as they usually have longer careers.

Using data from the Web of Science database, the researchers – led by physicist Albert-László Barabási from Northeastern University in the US – analysed the publication history of more than 1.5 million academics whose gender they could identify and who published their last paper between 1955 and 2010. The authors covered 83 countries and 13 scientific disciplines and the sample included a third of all papers published between 1955 and 2010. Barabási told *Physics World* that this dataset allowed the team "to look at virtually the full career of everyone that we profiled, across all the fields, without geographic boundaries".

The gender gap in productivity in the 1950s was around 10% and papers written by women had slightly more impact – based on the number of citations papers received 10 years after publication. But by the 2000s men were 35% more productive than women and received around 34% more citations.

Barabási and colleagues found that the proportion of female authors increased from 12% in 1955 to 35% by 2005. The researchers also found considerable gender differences between disciplines – in maths, physics and computer science just 15–16% of active authors were female, rising to around a third in psychology. Overall, male scientists were found to be more productive during their careers, publishing an average of 13.2 papers per year, while women published 9.6 – a productivity gap of 27%. And they also had more impact, receiving 30% more citations than women. But this gender gap was not always there. "The striking and the surprising news is that as [female representation increased] so did the gender imbalance in terms of impact and productivity," says Barabási.

When the researchers delved further into the scientists' careers, they discovered that gender differences in annual productivity were negligible. Female authors published an average of 1.33 papers per year, while men produced 1.32. The gender gap in career impact also disappeared when they matched males and females from the same disciplines with the same number of total publications, with women accruing 0.8% more citations.

Barabási says their work shows that the main reason there are gender differences in career productivity and impact is that women's careers end earlier. "A shorter career leads to lower career productivity – fewer papers published throughout their career – and also leads to lower career impact because the person is not around to support his or her work," he explains. On average, male scientists had a publishing career of 11.0 years, while female scientists published for only 9.3 years. Each year, 10.8% of women stopped publishing, compared with 9% of men.

According to the researchers, women are 19.5% more likely to leave academia than their male colleagues in a given year. This dropout gap persisted at a similar level throughout academic careers. To increase parity in career impact and productivity, Barabási told *Physics World* it is necessary to "focus very hard on keeping women in science".

Michael Allen

Philip Anderson: a legend is lost

The Nobel laureate Philip Anderson was a giant of condensed-matter physics, who was unafraid to speak out against what he saw as the excesses of particle physics. **Michael Banks** looks back

The US condensed-matter physicist Philip Warren Anderson, who died on 29 March aged 96, was one of the most celebrated condensed-matter physicists of the 20th century. His theoretical research into the electronic structure of magnetic and disordered systems led to an improved understanding of metals and insulators, for which he was awarded the Nobel Prize for Physics in 1977. He shared the prize with the British physicist Sir Nevill Mott and the US physicist John Hasbrouck van Vleck.

Born on 12 December 1923 in Indianapolis, Indiana, Anderson was raised in Illinois, where his father taught plant pathology at the University of Illinois in Urbana. In 1940 Anderson went to study physics at Harvard University but during the Second World War was drafted to work at the US Naval Research Laboratory, spending the period from 1943 to 1945 researching antenna design. He returned to Harvard, working on a PhD under the supervision of van Vleck, graduating in 1949. Anderson then joined Bell Telephone Laboratories in New Jersey, which was part of the telecoms firm AT&T. It was there that he developed his theory of the electronic structure of solids.

Much of what we know about the electronic properties of metals and semiconductors is based on the idea that electrons with certain momenta can travel freely through a crystalline lattice, while others cannot. This is embodied in Felix Bloch's 1928 quantum theory of conduction, which describes the lattice as a periodic electric potential through which some electrons (behaving as "matter waves") diffract with ease. In the 1960s, Anderson worked out what would happen in such a system if the potential lost its periodicity. This could happen, for example, if the lattice remained periodic, but the potential has a different value at each lattice site.

Anderson found that electrons would be unable to move through such a "disordered" lattice, and instead become trapped by specific atoms. If the disorder is sufficiently strong, the electrons cannot form an electric current due to destructive interference between different scattering paths. Instead, they become localized and unable to propagate in space.

Forward thinker Physicist Philip Anderson, who has died aged 96, made a vital contribution to our understanding of how electrons move in solids.

P W Anderson via Wikimedia Commons

It was for this prediction of what became known as "Anderson localization" that he was awarded the 1977 Nobel Prize for Physics, which he shared with van Vleck and Mott for their "fundamental theoretical investigations of the electronic structure of magnetic and disordered systems". Anderson localization has since been seen in several systems including those based on light, microwaves and in atoms held in a Bose–Einstein condensate.

A 'wonderful' lab

The 1960s was a particularly productive time for Anderson. He also worked on the theory of superconductivity, in which the electrons in a material can flow without resistance, and explored the properties of helium-3. From 1967 Anderson spent eight years on a part-time basis at the University of Cambridge, UK, before returning to the US to work at Princeton in 1975, while still being affiliated to Bell Labs.

Anderson retired from Bell Labs in 1984 when the US government disbanded AT&T, and he began working full-time at Princeton. There he continued his research on spin glasses – non-magnetic metals embedded with randomly spaced magnetic elements – as well as high-temperature superconductors, for which Anderson came up with his own theory for the effect called the resonating valence bond theory. The idea encountered some resistance within the community and the mechanism of high-temperature superconductivity remains to be resolved today.

In an interview with *Physics World* in 2006, Anderson said that he mostly enjoyed his 35 years at Bell Labs (see November 2006 pp10–11). "For the first three decades it was the most wonderful laboratory in the world," he said. "We had freedom, an enlightened management and a personnel department that never had any say in the direction of the research department. We had a very high opinion of ourselves, but it was justified. Those were the years when we invented modern technology."

The 'arrogance' of particle physics

Anderson also made crucial contributions to other fields in physics. In particular, in 1962 he published a now-famous paper on how the photon acquires mass (*Phys. Rev.* **130** 439). It was cited two years later by Peter Higgs in his own paper (*Phys. Rev. Lett*. **13** 508) on the discovery of a mechanism for understanding the origin of mass – a theory for which Higgs and François Englert won the 2013 Nobel Prize for Physics. The mechanism was later confirmed by the discovery of the Higgs boson at CERN's Large Hadron Collider in 2012.

While Anderson had noted that the Higgs boson could have been called the "Anderson–Higgs boson" in recognition of his work, in 2013 he told *Physics World* that the Swedish Academy made "a perfectly reasonable decision" to award the prize to Higgs and Englert (November 2013 pp6–7). "I also think the fuss over the theoretical part of the work a bit excessive relative to the gigantic experimental effort," he added.

In the late 1980s, Anderson was a vocal critic of the $4.4bn Superconducting Super Collider (SSC), which the US was planning to build in Waxahachie, Texas, as the next big machine in particle physics. In 1987 he famously gave testimony to the US Senate, in which he worried that the huge costs of the 87.1 km circumference circular collider would force cuts to other science budgets. He was far from the only physicist who had such concerns and, despite some $2bn eventually being spent on digging parts of the SSC's underground tunnel and constructing various buildings, the collider was cancelled in 1993, by which time the project's estimated final price tag had almost trebled to $12bn.

Indeed, Anderson held a sceptical view of particle physics and the belief held by some in the field that it deserved more funding than other areas. "There is a great arrogance and immodesty about that whole field, which gets on my nerves," he told *Physics World* in 2006. "Particle theorists say [they're] discovering 'the mind of God'. It's not the mind of God at all. In the first place, there's no God, and in the second place, particle physics cannot explain things like superconductivity, life and consciousness. It makes no contribution to explaining how the world actually works." He also held the view that particle theorists owe more than they realize to condensed-matter theorists like himself, particularly

Anderson held a sceptical view of particle physics and the belief held by some in the field that it deserved more funding than other areas

for having developed the concept of "broken symmetry" in the 1950s.

Emergent views

During his career, Anderson wrote several scientific books, including *Concepts of Solids* (1963), *Basic Notions of Condensed Matter Physics* (1997) and *More and Different* (2011). He also contributed to the philosophy of science, writing a now famous article "More is different" in 1972 (*Science* **177** 393). This set out the limitations of "reductionism", according to which all of science can, in theory, be derived from just a few fundamental principles. Anderson instead believed in "emergence", which states that everything we observe at one level obeys the laws at a more primitive level, but that those observations cannot necessarily be deduced from that level. He even dubbed it the "God principle" but told *Physics World* that it did not reflect any religious beliefs. "I'm not quite as atheistic as [Oxford biologist] Richard Dawkins, but I'm very close," he said.

Anderson received the US National Medal of Science in 1982 and was involved with the formation of the interdisciplinary Santa Fe Institute, which explores the science of complexity. He joined as an emeritus professor in 1985 and in 1996 Anderson became an emeritus professor at Princeton.

Outside physics, Anderson was a keen hiker and gardener as well as an enthusiast of the Chinese board game Go, in which he was a certified "first-degree master". But science was his true passion and Anderson remained active as a physicist well into his 80s and 90s, even being named as the "world's most creative physicist" by one statistical analysis in 2006 (September 2006 p9). He continued to review books, including a review for *Physics World* in 2013 of a biography of his near-contemporary Freeman Dyson, who died this February. His last letter to *Physics World* was published in 2017. He was also an honorary fellow of the Institute of Physics, which publishes *Physics World*.

Careers

Pregnant female PhD students face significant challenges

Female physics PhD students in Israel who are pregnant or give birth during their studies face significant challenges that could lead to substantial delays in progress. That is according to a comprehensive survey of students in the country, which uncovered high levels of discrimination and sexual harassment.

Yosef Nir, a theoretical physicist at the Weizmann Institute of Science, and his colleague Meytal Eran-Jona conducted a nationwide survey of all physics PhD students at Israel's six research universities. Of the 404 doctoral students in the academic year 2018/19, some 267 (66%) replied, including 60 women who made up 94% of female PhD students. Around 40% of survey respondents were parents. According to the researchers, Israeli society differs from other Western societies as people marry younger and have more children, on average. Doctoral students also tend to be older as graduate studies are delayed due to compulsory military service.

According to the survey, 95% of mothers and 86% of fathers stated that becoming a parent affected their studies. Mothers took much more parental leave, with 69% having four months' leave – the standard by law. In contrast, only 16% of fathers took more than month off and more than half (58%) had none at all. "The academic community [in Israel] strongly believes that all academic decisions and procedures are based on meritocracy, and that the academic institutes are gender-neutral," Nir told *Physics World*. "What is lacking is, first, the acknowledgement that due to social circumstances the playing field is not level and, second, that the phenomena of sexual harassment and gender-related discrimination exist."

Female PhD students with children also took on more of the family load than their male counterparts. When asked who does most of the childcare in their household, 57% of mothers responded that they do, compared with just 5% of fathers. No women said that their spouse is the main caregiver for their children – or responsible for most household chores. "The most significant difficulties that are far from being gender-neutral are the challenges related to pregnancy and motherhood, the fact that the female PhD students either share or take the main responsibility not only on childcare but also on household tasks," Nir says.

There are also significant differences in discrimination, with 67% of women having experienced it, compared with only 19% of men. Half of those women said it was linked to their gender and 19% to pregnancy or parenthood, while men rarely mentioned these factors. About a fifth of women experienced sexual harassment during their studies, compared with 2% of men.

To tackle these issues and support women pursuing physics careers in Israel, Nir says the academic community needs to address sexual harassment, promote a discrimination-free environment and adopt institutional policies that consider "the special hurdles for women".

Michael Allen

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Bump in the road A study of students in Israel found that two-thirds of women suffered from discrimination.