Find the magic formula and you can recreate the most exotic of cosmic objects in the humblest of settings, finds Sophie Hebden

Small world, big physics

IN MANY an unassuming corner of the globe, you might come across an attic, shed or spare room with a table-top railway. To the uninitiated, these model train sets, with tiny figures standing at platforms and tracks fringed by green sponge bushes, represent a harmless, if peculiar, pastime. To the hobbyist, they are a serious affair – a labour of love, and a way to run a railway almost as if for real.

This spirit of tinkering, of exploring and learning about the real world by making smaller-scale models of it, is also alive in the physics lab. Many desirable things lie beyond the practical reach of physicists: recreating the first moments of the universe, playing freely with high-energy particles, wandering the fringes of a black hole.

And so on bench-tops across the world, you'll see odd apparitions. Whether a black hole fashioned from water waves, or a Higgs boson sculpted from liquid helium, these are "analogues" – lovingly crafted replicas of physical systems that, primed in the right way, can be made to work just like the original. The hope is they might help overcome some of the practical and financial limitations of larger experiments, and themselves become an engine driving our understanding of the real world.

The idea of doing physics without actually doing it is not new. Purely hypothetical

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thought experiments have long been used to investigate the consequences – or perhaps absurdities – of physical theories, from ancient Greek times right up to these modern days of relativity and quantum theory. In recent years, powerful computers have given a new way to simulate physical processes, as they roam through lines of code to explore the mathematics that underlies a phenomenon.

Precise replica

But number-crunching has its limitations. “There are still many unanswered questions about these systems, and we can only include in our computer codes what we already know about them,” says Daniele Faccio of Heriot-Watt University in Edinburgh, UK. Analogues work differently. Mathematics is the universal language that underlies physics, and often the same equations pop up in seemingly unrelated areas. Find two physical systems that run according to the same rules, and you can substitute one for the other, crafting a precise replica of the phenomenon you are interested in using materials that exactly emulate the underlying mathematics. “It isn’t the same as using the original system, but it’s always more interesting than using a computer model,” Faccio says.

Take the Higgs boson. This particle was the final missing piece in the jigsaw of the standard model, the theory that explains how quantum particles interact through three of nature’s four fundamental forces. According to an idea first floated in the 1960s, the vacuum is permeated by an invisible field, the Higgs field, that “sticks” to fundamental particles to different extents, giving them different masses. Prod this field by injecting a large enough amount of energy into it, and it manifests itself more tangibly: a Higgs boson pops out of the aether.

The discovery of this particle was finally announced to the world in July 2012 by researchers at the Large Hadron Collider (LHC) at CERN, near Geneva, Switzerland. One reason it took so long was that, although we knew it would take a lot of energy to make a Higgs, no one knew quite how much. In the end, it could only be found by building a monstrous particle-smashing machine and sifting through the wreckage of many billions of high-energy particle collisions within it.

Perhaps we made things harder than they needed to be. When the idea of the Higgs was mooted by theorists in the mid 1960s, a similar idea was already doing the rounds among physicists studying low-temperature superconductors. In these curious materials, pairs of electrons begin to interact with each other and the surrounding lattice of atoms, leading to the creation of particle-like entities known as Cooper pairs. These pairs move freely, encountering no electrical resistance.

This magic happens only in materials cooled to within a whisker of absolute zero, about -273 °C – but the mathematics describing the process is almost identical to that describing the higher-energy Higgs interactions. While it is not easy to stoop to such low temperatures, the kit needed to do it is considerably smaller and cheaper than a particle accelerator. Observing the equivalent processes in the superconductor might provide crucial clues as to how the real Higgs boson is made (see diagram, page 38).

It took a while to realise all of this. Tom Kibble of Imperial College London was one of six physicists who in 1964 came up with the idea of the mass-giving Higgs mechanism. But at the time, he and his colleagues hadn’t quite grasped the significance of what the superconductor theory was already turning up. “We were certainly aware of this suggestion, but we didn’t understand it very well – at least, I didn’t,” he says.

It was a similar story in 1981 when the signature of a Higgs-like creature was actually spotted within a superconductor. At the time, this was a bit of a sideshow. Then, the theory of low-temperature superconductors was well-established, and finding the analogue of the Higgs was just another, slightly incidental confirmation of it. In particle physics, meanwhile, the theorists were still scrabbling for any experimental confirmation at all of their idea for how matter gained mass. “We didn’t realise how big the Higgs would become,” says Peter Littlewood of Argonne National Laboratory in Illinois, who helped to interpret the superconductor experiments.