From boiling water to the utmost quantity

Van Der Waals' work is still relevant a century after his Nobel Prize

A hundred years ago this month, Leiden's own Johannes Diderik van der Waals was awarded the Nobel Prize.

BY BART BRAUN Leiden University always attributed considerable importance to classical languages. In fact, Johannes van der Waals, a maths teacher and native of Leiden, was not permitted to sit the exams for his physics course in 1862 because he had never attended any Latin or Greek classes. The Minister of Education had to grant him dispensation so that he could complete his studies. His Leiden dissertation was published in 1873 and immediately received an enthusiastic review from the eminent physicist James Clerk Maxwell, who predicted that there would be more than one researcher set on learning Dutch.

Nobel Prize winner Johannes Diderik van der Waals (1837-1923).

Over de Continuiteit van den Gas - en Vloeistoftoestand [On the Continuity of Gaseous and Liquid State] was a real scientific breakthrough. Not long after its publication, Van Der Waals was given a professorship at the brand-new University of Amsterdam. He received the Nobel Prize for his work in 1910, precisely a hundred years last Thursday, on the occasion of which the Boerhaave Museum organised a symposium.

The most important pillar of Van Der Waals' work is his equation of state: a physical formula that expresses the relation between different quantities. The most famous one is Boyle and Gay-Lussac's ideal gas Law: if the quantity of gas remains equal, the pressure times the volume divided by the temperature will remain constant. This law helps explain why a bag of crisps on an aeroplane will start to bulge: the air pressure drops so the volume must increase.

Van Der Waals' Law is also an equation of state, but it is more complicated. Boyle and Gay-Lussac regarded the gas molecules as points, but Van Der Waals realised that the gas particles behave like hard spheres and, consequently, the ideal gas law does not apply at higher pressures: the molecules get in each other's way. Van Der Waals also demonstrated that his law applies to liquids as well as gasses. In 1913, Heike Kamerlingh Onnes won the Nobel Prize when he proved that Van Der Waals' calculations were correct by liquefying helium.

"Thanks to Van Der Waals, new life was breathed into these states of equation," explains Professor of physics, Jan Zaanen. "He explains why you can have both water and steam; you can deal with both states using Van Der Waals' formulas."

At the symposium, Zaanen, winner of the Spinoza Prize, discussed the relevance of the state of equation for modern physics. "These equations have always been essential for physics. The most important themes in physics all have their own equations of state, or else, physicists are trying very hard to find them."

Zaanen divides the themes into three categories: extremely cold, extremely hot or extreme quantities. Those who are following in Kamerlingh Onnes' footsteps and calculate absolute zero (-273° C) to several billionth of a degree come across some completely unfamiliar physics. Gasses suddenly become superconductors, or substances that – according to your high-school course books – should not exist, are created and start forming Bose-Einstein condensation. "But exactly on the boundary between those two situations, you find a unitary Fermi gas with all sorts of strange qualities, such as an infinitely strong reciprocity between the particles", adds Zaanen. "If you really understand what is happening, then you will also know what you do and don't understand in other disciplines. And you can express that comprehension in an equation of state."

In extreme heat, quark-gluon plasmas are formed, a churning soup of elementary particles like the ones created just after the Big Bang. Physicists have been attempting to reproduce these plasmas in large particle accelerators. When they recently succeeded, it emerged that quark-gluon plasmas have scarcely any viscosity – syrupiness - at all: they are more liquid than any other liquid there is. Zaanen says: "To understand how that works, you have to know the equation of state. Supercomputers are busy calculating it, but to everyone's surprise, the string theory has proved to be very useful for explaining it."

Professor Jan Zaanen: "Dark energy is the most wonderful mystery in the history of physics"

The string theory is a mathematical approach that presents these elementary particles as vibrating strings. It was criticised for many years: great maths, but no predictions that could be tested by an experiment. This work – and Zaanen's calculations for superconductors – demonstrates that the string theory really does have its uses. "At last, the string theorists have achieved something", says the Professor excitedly.

"Utmost quantity" refers to the utmost quantity in existence: the universe itself. Calculations for the expansion rate of the universe indicate that approximately three quarters of all the mass in the universe must consist of dark energy. This dark energy acts as a negative pressure, forcing everything in the universe apart. "That is pressure as in the gaseous pressure mentioned by Van Der Waals," explains Zaanen.

Astronomers can tell how large the universe is by looking at it, and physicists can calculate what its size must be with lab experiments. So far, their results differ immensely: by a factor of 1 with 120 zeros. Zaanen adds: "It's the greatest problem in physics at the moment."

While waiting for better data, the scientists are keeping their cards close to their chests. Zaanen says: "But whatever the definite measurements are: we know the most important qualities of the equation of state of the universe. We can move from Van Der Waals' boiling water to the properties of space and time. Dark energy is the most wonderful mystery in the history of physics: we know that there is something that we do not understand at all."

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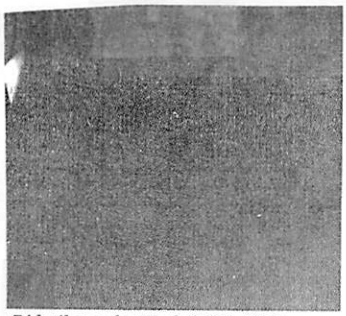

; Diderik van der Waals (1837-1923).

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