Afterword: Maxwell's Demon

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PROBABLY ONE OF the more famous of the thought experiments, Maxwell's imagined demon is an attempt to directly violate the laws of thermodynamics though a mischievous demon between two boxes of gas.

The laws of thermodynamics were formulated in the 1800s and are, even now, are important pillars of the modern scientist's view of the world. The laws tell us about how heat works and provides an arrow to the flow of time. The zeroth law states that if two systems are separately in thermal contact with a third system and no heat flows, then no heat will flow if the two systems are in thermal contact with each other. This sounds trivial, and it is, but helps us make sense of ideas like temperature and temperature scales like "degrees Celsius". So we find it useful to write down a seemingly simple statement. This zeroth law helps define something important called 'thermal equilibrium', which is what two systems are in when they are connected but no heat flows between them. Happily the first law is more interesting and essentially says that energy is conserved. More precisely, it says that if I heat a system or push on it (do work to it) then that system's internal bookkeeping measure (recording how much energy is contained) must show an increase by exactly the right amount. It also says that how the heat is applied to the system, or how the work is done to it, does not matter. Only the total amount matters in the end. There's a nice equation that comes with the law that lets us understand phenomena like compression of a gas, heat capacities of substances or fluid flow. Next we come to the second law, which has by far and away the most forms and is, by far and away, the most interesting. Imagine we only had the zeroth and first laws. Then heat could flow from one body to the next but there is nothing to say which way the heat flows. This means heat could flow from a cold body like an ice-cube to a hot body like a cup of tea and not violate the laws of thermodynamics. However if we look at nature we see a natural direction for change – heat flows from a hot thing to a cold thing and gives a sense of direction. The second law fixes this by making a statement about the irreversibility of nature. In the (paraphrased) words of German physicist Rudolf Clausius:

"No process is possible whose sole result is the transfer of heat from a colder to a hotter body"

So heat flows from a cup of tea to an ice-cube. There is also a more intriguing formulation of the law, involving entropy. This word is a posh scientific way of talking about disorder and the fact that we know the universe likes to move to a more disordered state. A trivial example is that tea cup can fall and break into many pieces but tends not to spontaneously unbreak and form a perfect tea cup from the many little pieces. More precisely the second law of thermodynamics states that the entropy (disorder) of an isolated system cannot decrease. This immediately provides an arrow of time and means systems tend to get more disordered with time.

What has this got to do with Maxwell? He was working, shortly after the laws were formulated, on a pioneering microscopic theory of gases and wanted to explicitly 'pick a hole' in the second law and show it only had 'a kind of statistical certainty'. To do this he imagined his demon that was able, by controlling a little window between a box of hot gas and a box of cold gas, to effectively make heat flow from the cold gas to the hot gas. This was done by preferentially opening the window when 'cold' gas molecules (on the hot side) headed towards the window, letting them through to the cold side, and vice versa with 'hot' molecules on the cold side. This would make the hot side hotter, and the cold side colder, directly contravening the second law and preventing the inevitable rise of entropy.

It took almost 100 years for the resolution to this thought experiment to be discovered. The first counter-argument came from the act of measurement itself, and the fact that the demon would have to expend energy to measure the gas molecules as they came near – thus increasing entropy. This argument stood until it was pointed out that, in principle, the demon could make a measurement without expending energy but at the cost of storing all the

information gathered during the measurement process. The demon, presumably being a finite being, would not have infinite storage and eventually would have to erase old data to make way for new. These are the beginnings of arguments founded on information theory, which are of central importance today in fields such as computation and quantum mechanics, and with them Maxwell's demon was finally dispelled.

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