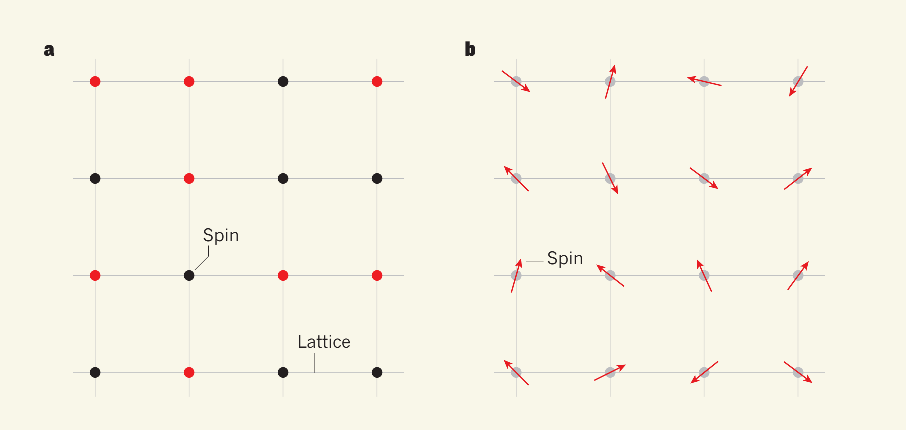

Figure 1 | The Ising and Heisenberg models. a, Two-dimensional magnetic systems consist of magnetic moments (spins) arranged on a lattice. Huang *et al.*[2] show that atomically thin layers of chromium triiodide (CrI_3) are well described by the Ising model[3], in which spins are constrained to lie perpendicular to the plane of the lattice: either into the plane (black) or out of the plane (red). **b,** Conversely, Gong *et al.*[1] find that the properties of ultrathin layers of chromium germanium telluride ($Cr_2Ge_2Te_6$) are consistent with the Heisenberg model[4], in which spins are free to point in any spatial direction. The two groups demonstrate that, below a critical temperature called the Curie temperature, both CrI_3 and $Cr_2Ge_2Te_6$ exhibit ferromagnetism, whereby all the spins point in the same direction.

techniques — in which materials are grown over the top of a substrate in a layer-by-layer fashion — extended these adventures in magnetic 'flatland' closer to ideal 2D systems[6]. Such techniques allowed ultrathin magnetic films to be studied, but these films had unavoidable imperfections. A generalized method for creating truly 2D ferromagnets has until now not been demonstrated.

Since the discovery[7] of graphene in 2004, there has been a vast exploration of flatland using ultrathin films exfoliated (removed) from van der Waals crystals — crystals held together by short-range van der Waals forces[8]. Although many phenomena associated with the quantum behaviour of electrons have been observed using this approach[9], the ferromagnetic ordering of spins in a single atomic layer has been particularly elusive, requiring a technique of much greater sensitivity than that provided by conventional magnetometers. To achieve the necessary level of sensitivity, Gong *et al.* and Huang *et al.* use a method called polar magneto-optical Kerr effect microscopy to determine the spatial extent of ferromagnetic order in their materials. This technique uses the rotation of linearly polarized light to spatially map out the direction and magnitude of spins, with micrometre spatial resolution[10,11].

In their 3D crystalline form, CrI_3 and $Cr_2Ge_2Te_6$ have similar properties. First, they display ferromagnetic order at temperatures below 61 kelvin[1,2] (known as their Curie temperature). Second, they have a distinct magnetic anisotropy[12,13] — their response to a magnetic field depends strongly on the direction of the field. And finally, they are soft ferromagnets, meaning that the spins of the chromium atoms are readily aligned when a magnetic field is applied in a specific direction, but they do not remain aligned when the field is removed. However, the authors show that the properties of these materials differ when the layers approach the 2D limit.

Huang and colleagues demonstrate that ferromagnetic order remains intact in CrI_3 even in a single layer of the material (albeit with a suppressed Curie temperature of 45 K). Unlike the case of the 3D crystals, the authors show that a single layer of CrI_3 has a substantial remnant magnetization in the absence of a magnetic field, directed perpendicular to the plane of the lattice. The magnetic system is therefore well described by the 2D Ising model[3], in which spins are constrained to lie perpendicular to the plane (Fig. 1a). Remarkably, Huang *et al.* find that the nature of the ferromagnetic order in CrI_3 is highly sensitive to the number of layers in the system. In a bilayer, the remnant magnetization present in a single layer is suppressed — consistent with the two layers having oppositely oriented spins (an antiferromagnet). Conversely, in a trilayer, this cancellation is lost and the net magnetization is recovered.

Gong and colleagues show that, in strong contrast to CrI_3, ultrathin layers of $Cr_2Ge_2Te_6$ have a highly suppressed Curie temperature in the 2D limit (for example, about 30 K for a bilayer). Consistent with the Mermin–Wagner theorem[4], the authors demonstrate that ferromagnetic order is not present in a single layer of $Cr_2Ge_2Te_6$ — at least down to the lowest temperature studied (4.7 K). Furthermore, $Cr_2Ge_2Te_6$ always remains a soft ferromagnet that has an extremely weak remnant magnetization perpendicular to the plane of the lattice. By comparing their results with theory, the authors show that the magnetic behaviour of $Cr_2Ge_2Te_6$ in both the 2D and 3D regimes is well described by the Heisenberg model[4], in

NATURE

50 Years Ago

It seems generally accepted that the eucaryotic cellular form … has developed from procaryotic forms … It often seems to be taken for granted that the transition took place in such a way that one procaryotic cell has developed into a eucaryotic one. It may, however, be just as fruitful to discuss the possibility that one eucaryotic cell has evolved from a number of procaryotic cells … With oxygen in the atmosphere … aerobic procaryotes must have developed. We can then assume that some of the anaerobic eucaryotes established an endocellular symbiotic relationship with aerobic procaryotes … During further evolution, the aerobic partner must necessarily have lost a great part of its autonomy … The final step in this evolutionary process would be the development of mitochondria as we know them from eucaryotic cells today.
From *Nature* 10 June 1967

100 Years Ago

Writing in 1684, Andrew Symson, minister of Kirkinner, records in his "Large Description of Galloway" that "in this parish [Glasserton] there is a hill called the Fell of Barhullion, and I have been told, but I give not much faith to it, that the sheep that feed there often have commonly yellow teeth, as if they were guilded." In this matter the worthy minister was unduly sceptical. The Fell of Barhullion is on my property, and jaws of sheep fed thereon have been brought to me with the teeth thickly plated with iron pyrites. The rock of the district is Lower Silurian; in the softer parts (Moffat Shales) large nodules of iron pyrites are found. As there is wet peaty soil on parts of the fell there is no lack of humic acid.
From *Nature* 7 June 1917