(*Cyanistes caeruleus*; Fig. 1) in southern Germany, and related these to the presence or absence of their female partners. Schlicht and colleagues first tagged the birds with radio-frequency-identification (RFID) tags to enable the location of the animals to be determined. They then placed an automatic RFID recorder near the nest box, and used this system to determine whether the female was inside or outside the nest box.

After filtering the recordings to make sure that the bird of interest was the one singing in the recordings, Schlicht *et al.* found that the males sang at high rates while their female partners were still roosting in the nest box at dawn, and stopped singing as soon as the females left the nest box to join them. Similarly, males were more likely to sing when the females went to roost in the evening, and song rates also increased whenever the females entered the nest box during the day.

Interestingly, male song rates increased in a linear manner as separation time from the female increased during the day. However, this linear relationship predicts an impossibly high dawn song rate after overnight separation, which was not observed.

To check for any extra support for the generality of their hypothesis, the authors searched published work and found some circumstantial evidence that males and females of most species show a mismatch in their daily activity, leading to separation periods at dawn and dusk. Furthermore, several studies (but not all) indicate that male singing activity increases when a female partner is separated from the male in the context of experimental manipulations.

The patterns found for blue tits are exciting for this field, and do convincingly fit this female-absence hypothesis. They also provide support to observations that show similar patterns in other species. However, further work will be necessary to determine whether Schlicht and colleagues' hypothesis describes a universally applicable mechanism for the dawn chorus. Birdsong in males has a dual function. It is used to defend territories against other males and to attract females, and which of these two roles is dominant varies between species and can depend on the breeding stage for a given species[7].

Schlicht *et al.* conducted their study during the ten days around egg laying. This is the fertile period of the blue tit, one of the species in which male dawn singing reaches a maximum at this precise stage of the breeding season when the female is inside the nest. Thus, the change in male singing activity in relation to the presence of a fertile female about to mate makes sense from a mate-guarding perspective. The male cannot guard the female from copulation attempts by other males when she leaves the nest if he sings when she is outside the nest[2,8].

However, not all bird species sing during the female's fertile period: some even become completely silent at this time[9]. In addition, dawn choruses can happen throughout the breeding season, by males engaging in feeding chicks and even by unpaired males. It remains to be determined whether, in situations such as those and when females are no longer fertile, the singing patterns found in this study also occur.

The female-absence hypothesis offers a mechanistic explanation for the dawn chorus, but the authors do not propose an evolutionary function. Rather, Schlicht and colleagues speculate that, possibly after an origin not related to evolutionary processes of natural selection or mate choice by sexual selection, a full range of functions mediated by this singing might have been acquired over time, such as strengthening the pair bond, manipulating female behaviour or displaying male quality.

This phenomenon nevertheless begs for a functional explanation. Although the first of the two conditions of the hypothesis (separation between males and females at dawn or dusk) could be explained by an origin due to inherent sex-specific differences under natural selection, the second condition (less singing when the female is present) strongly suggests that this pattern of singing has a function. And even if the patterns predicted by the female-absence hypothesis can be applied to other species, we need to address the following key question. Why do males sing more when females are absent or less when females are present?

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Condensed-matter physics

New type of magnetism splits from convention

Carmine Autieri

Magnetic materials with zero net magnetization fall into two classes: conventional antiferromagnets and altermagnets. Physicists have identified a property in altermagnets that widens the divide between the two groups. **See p.517 & p.523**

The energies of electrons in a material are confined to specific levels. These levels can split into bands that correspond to possible configurations of the electrons' intrinsic angular momentum — their 'spin'. Such spin splitting underlies the existence of ferromagnetism: the type of magnetism found in iron. But it has also been predicted to arise in materials showing a newly discovered type of magnetism, known as altermagnetism, and such systems could prove more useful than ferromagnets for some technological applications. In two papers in *Nature*, Krempaský *et al.*[1] (page 517) and Zhu *et al.*[2] (page 523) report experimental evidence of spin splitting in materials classed as altermagnets.

Energy levels are said to be degenerate if they correspond to two or more quantum states. In 1930, the Dutch physicist Hans Kramers found that a particular type of degeneracy — now known as Kramers degeneracy — exists in non-magnetic systems that show time-reversal symmetry (those that adhere to the same laws of physics whether time runs forwards or backwards)[3]. Kramers degeneracy was subsequently found to exist in all non-magnetic systems.

But what about magnetic systems? Kramers degeneracy is thought to extend to antiferromagnetic systems, the name of which refers to their relationship with ferromagnetism. The spins in ferromagnetic materials all point the same way, but in antiferromagnets, adjacent spins are oriented in opposite directions, so the net magnetization of the material is zero. However, Kramers degeneracy has never been

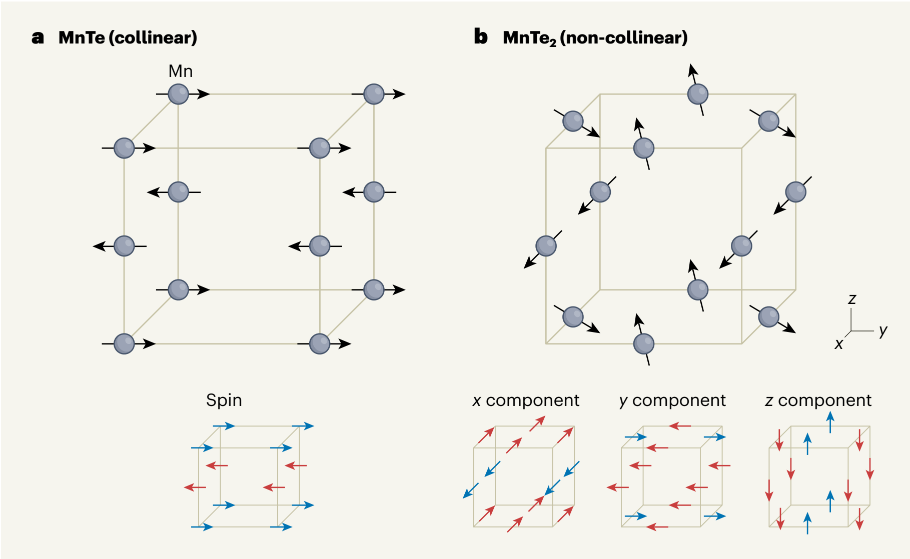

Figure 1 | Configurations of altermagnets. Antiferromagnets are materials in which the intrinsic angular momenta (spins) of electrons are oriented in opposite directions, so the net magnetization of the material is zero. Altermagnets form a class of antiferromagnet, and have been predicted to show a phenomenon called spin splitting. **a**, Krempaský *et al.*[1] found evidence of spin splitting in the altermagnetic compound manganese telluride (MnTe; Te atoms not shown because they are non-magnetic), which is collinear, meaning its manganese spins are aligned along a single axis. **b**, Zhu *et al.*[2] showed that manganese ditelluride ($MnTe_2$) also displays spin splitting. $MnTe_2$ is non-collinear, but can be decomposed into three collinear altermagnets, each representing a spatial component of the manganese spins, leading to complex spin-splitting properties.

verified rigorously for antiferromagnets.

In the past few years, physicists have begun forming theories about the possibility that there are specific limits to the extent to which Kramers degeneracy applies to antiferromagnetic systems[4,5]. This led to a categorization of antiferromagnets – those that show Kramers degeneracy are now called conventional antiferromagnets, whereas those that lack it are termed altermagnets. The definition of an altermagnetic system is tied to specific crystallographic symmetries, and these symmetries are surprisingly widespread, so a considerable portion of antiferromagnetic systems are classified as altermagnets under this revised definition.

The key to obtaining crystallographic symmetries that host altermagnetism lies with the non-magnetic atoms in a material, and the way that they affect its magnetic symmetries. The role of these atoms has long been disregarded in solid-state physics, and is only now being given full consideration. The absence of Kramers degeneracy is the reason that the system's energy levels split. This spin splitting occurs in ferromagnets and altermagnets of a comparable size. It imbues altermagnets with some properties that are similar to those of ferromagnets, while maintaining zero net magnetization.

These similarities are technologically promising, because antiferromagnetism occurs in a broader range of materials than does ferromagnetism. It also tends to appear at higher temperatures than ferromagnetism, which often requires cryogenic cooling. And there are other benefits: the magnetization of ferromagnets can induce stray magnetic fields that interfere with the material's performance, but these fields do not arise in antiferromagnets. Finally, oscillations in magnetization can be used to produce high-frequency signals, and antiferromagnets can achieve higher-frequency oscillations than can ferromagnets[6]. These attributes underline the potential importance of antiferromagnetic systems in various applications[7].

Krempanský *et al.* used a technique called X-ray angle-resolved photoemission spectroscopy (ARPES) to investigate the electronic and magnetic characteristics in manganese telluride (MnTe). The surfaces of materials often host altermagnetic surface states that can differ from their bulk counterparts. By using X-ray ARPES, the authors were able to bypass these surface effects and characterize the bulk of the compound. Their study provides robust evidence for spin splitting in MnTe, suggesting that it is present in a large share of antiferromagnetic compounds.

MnTe is a 'collinear' altermagnet, which means that the spins of manganese atoms point in opposite directions but are oriented along the same set of axes (Fig. 1a). However, altermagnets can also be non-collinear. In this case, their spins are not parallel, because of factors such as interactions or the geometry of their crystal structure, but they still show the zero net magnetization that is indicative of antiferromagnetism.

Zhu *et al.* studied manganese ditelluride ($MnTe_2$), which is non-collinear, using a method known as spin-resolved ARPES. The authors showed that spin splitting in this system results in manganese spins assuming a plaid-like pattern. This non-collinear altermagnet can be decomposed into three collinear altermagnets, each representing a spatial component of the manganese spins (Fig. 1b) and each giving the material a different spin-splitting property.

Although the two groups used different experimental approaches and methods of analysis, both studies contribute key advances to the understanding of spin splitting in altermagnetic compounds – they shed light on the complexities inherent in the magnetic structures of these materials. The authors' work will no doubt serve as a catalyst for accelerating research on this topic. One direction for future investigation is the effect that electric fields have on altermagnetism. Another is the surfaces and interfaces at which altermagnetic properties can be tuned.

A third possibility involves the appearance of ferromagnetism in altermagnetic compounds. Although altermagnets have zero net magnetization, ferromagnetism can be induced in these materials through a phenomenon called spin–orbit coupling, which involves an electron's spin interacting with its orbital motion. This effect is often weaker than conventional ferromagnetism, and for this reason it is termed weak ferromagnetism[8]. Improved understanding of altermagnets could lead to technologies for engineering and manipulating weak ferromagnetism[9,10].

These emerging concepts are poised to become integral components of future physics textbooks. Although current research on altermagnets is mainly fundamental in nature, it is likely that the insights garnered by these two papers will pave the way for technological applications in the coming decades. The enticing results will undoubtedly form a cornerstone of exciting developments.

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