

## CELL DIVISION

## Running rings around the spindle

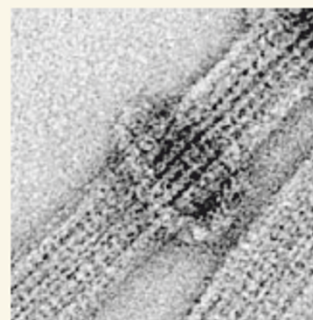
When cells divide, each chromosome is duplicated and one copy is passed to each daughter cell. The details of how these duplicated chromosomes are separated are still being puzzled out, but elsewhere in this issue, Georjana Barnes and colleagues (*Nature* **440**, 565–569; 2006) add a large piece to the jigsaw.

During cell division, an array of tiny filaments called microtubules spreads from the poles of the cell to the central plane, where the duplicated chromosomes congregate. This microtubule structure — the 'mitotic spindle' — is responsible for dragging the two copies of the chromosome apart into the two regions that will form the daughter cells. Microtubules are linear polymers of the protein tubulin of diameter 24 nm that grow or shrink as tubulin monomers are added to or lost from their ends. During chromosome segregation,

the microtubules depolymerize, and thus shorten, from the end nearest the central plane of the cell. So, as the spindle shrinks, the attached chromosomes are carried towards the pole.

The chromosomes stick to the depolymerizing ends of the spindle microtubules through specialized protein complexes known as kinetochores. But if these ends are continually dissolving as the microtubules pull back, how do the chromosomes stay attached? The answer lies with a subcomplex in the kinetochore, called the Dam1 complex, which assembles into rings and paired helices that encircle the ends of depolymerizing microtubules (pictured).

Barnes *et al.* used real-time imaging to watch the Dam1 complex on dynamic microtubules *in vitro*. They labelled the Dam1 complex and the microtubules with different coloured fluorophores. As the



microtubules shortened during depolymerization, the Dam1 complex could clearly be seen progressing along the microtubules. This movement could be explained either by a 'sliding' mechanism, in which the Dam1 complex is continually associated with the microtubule lattice, or by a 'turnover' mechanism, with new subunits of the Dam1 complex rapidly incorporating into existing rings as old subunits leave, thus propelling

the ring along the microtubule. The authors demonstrated that turnover of Dam1-complex subunits was not taking place and that the ring structure is sliding intact along the depolymerizing microtubule.

Finally, Barnes and colleagues showed that the Dam1 complex can function as a coupling device to move objects along the microtubules. These experiments relied on the strong bonds formed between streptavidin and biotin molecules. Streptavidin-coated microbeads were recruited to the microtubules using a biotin-labelled Dam1 complex. As the microtubules depolymerized, the Dam1 complex slid along the spindle away from the shrinking ends, bearing its cargo of beads. It will be interesting to find out whether chromosomes are transported in the same way. **Deepa Nath**

G. BARNES ET AL.

the same quantum state), and the atomic-pair potential diverges steeply towards infinity as  $r$  approaches zero. And at the mesoscopic scale — that between the microscopic and the macroscopic — the rigid core of colloidal particles ensures that they just 'bounce off' each other at low separations, and also do not overlap. Neither the atomic nor the mesoscopic potentials even possess a Fourier transform; for a long time, finite interactions of the type considered by Sütő<sup>1</sup> were simply considered 'unphysical'.

But effective potentials between the centres of mass of entities such as block copolymers<sup>2</sup>, polymer chains or dendrimers can indeed remain finite at zero separation (Fig. 1). Theory<sup>3</sup> and simulation<sup>4</sup> have shown that the effective potential between two chains has a gaussian form, and calculations have shown that its ground-state configuration is face-centred cubic (fcc) at low densities and bcc at high densities<sup>5,6</sup>. Fourier transformation does not change a gaussian form, so  $\phi(k)$  is positive in this case. There is, however, no value of  $K_0$  above which  $\phi(k)$  is zero, so Sütő's result is not valid here. Nevertheless, his work joins a rapidly growing body of research<sup>7</sup>, spurred on by developments in soft-matter physics, on the properties of bounded interaction potentials in one-component systems, in which the properties of  $\phi(k)$  are used to obtain information on the ground-state configuration or the topology of the phase diagram.

A potential  $\phi(k)$  that vanishes above a

threshold seems difficult to realize physically. Sütő shows that the requirement for this to occur leads to an interaction potential that shows oscillatory behaviour combined with a power-law decay at large values of  $r$ . This is strikingly similar to the RKKY (Ruderman-Kittel-Kasuya-Yosida), or Friedel, potential<sup>8–10</sup> that arises as an effective interaction potential between ions when the effect of free electrons is incorporated as a statistical average. For metals of valency  $Z$ , the ion density  $\rho$  is related to Sütő's minimum density by  $\rho = \rho^* \pi \sqrt{2}/(3Z)$ , so that  $\rho$  exceeds  $\rho^*$  by 48% for  $Z=1$  and trails it by 26% for  $Z=2$ . So unfortunately there is no happy agreement between the real and the Sütő densities that would hint at why certain metals crystallize into the bcc structure. The power laws governing the behaviour of the RKKY and Sütő potentials at large values of  $r$  are slightly different, and effective ion potentials also include a steeply repulsive region at small values of  $r$  (ref. 10) that is absent in Sütő's interaction. So the long- and short-range parts of the potential must be considered independently. Sütő provides us with a suitable reference frame to deal with the former.

In the late 1970s, a celebrated and controversial article<sup>11</sup> was published entitled 'Should all crystals be bcc?'. It contained a theory of freezing that involved density waves — modulated density profiles — at the set of reciprocal lattice vectors  $K$  as parameters in a mathematical expression for the free energy. On the basis

that the bcc crystal is the only spatial configuration that combines the shortest reciprocal-lattice vectors lying on the surface of a sphere, it was concluded that the stablest crystals should all be bcc. This argument, although brilliant, was flawed in making certain simplifying assumptions. Sütő's work comes from a very different direction to again put the bcc lattice in a distinctive position among all Bravais lattices. In this way, it recasts the question of why crystals form as they do in a fresh and thought-provoking way. ■

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