How to Move in a Jostling Crowd

The Art of Harnessing Random Motions

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For people living in big cities it is an ordeal to walk in a bus stand or a railway station. They get stuck helplessly in a crowd. They are simply pushed around and all their efforts to move forward appear futile. Only the most energetic can wade through the constantly moving sea of people. How about the weaker ones ? Now there is a way out even for them, provided they emulate the bug *Listeria manocytogen*.

These bacteria cause the disease meningitis. They have the special knack of swimming in water by exploiting the random motions of the water molecules i.e., Brownian motion. When Brownian motion kicks this bacterium forward, the microbe for a moment allows itself to be pushed. Then it quickly anchors itself in the new place until it gets another push forward. The bacterium accomplishes this extraordinary feat with the help of its bushy tail. So next time you get mixed up in a crowd you can navigate across like this deadly pathogen. Allow the crowd to push you if it is in the right direction. Otherwise stay firmly wherever you are. Thus you can skillfully get out of the mess. *Listeria's* talent for turning random thermal motions into net movement has attracted the attention of scientists because it extracts work out of something generally regarded as useless 'noise'.

Are there other schemes for harnessing Brownian motion? In this context it is instructive to remember what Feynman said about thirty years ago. He used a ratchet as an example to argue that useful work cannot be extracted from equilibrium fluctuations. A ratchet is a mechanical device that can turn only one way. In recent years it has been realised that the same restrictions do not apply to non-equilibrium noise. In other words an asymmetric potential can rectify symmetric fluctuations. In common parlance this means that structures with spatial asymmetry can act as 'ratchets' for randomly moving particles. This means that under the influence of such a structure the randomly moving particles start drifting in a particular direction.

In view of such implications, ratchets have become important and fashionable systems to study. In 1994 Rousselet and co-workers came up with an electrical device that acted as a ratchet. They built a microelectrode

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system which generated a periodically appearing and disappearing saw-tooth electrostatic potential. In a medium of randomly moving colloidal particles this device pushed forward small particles of sizes 0.1 to 0.5 microns. Interestingly, the velocity of the forward motion appeared to depend on the particle size. Hence these authors also suggested that their device can even separate particles of different dimensions. How this actually works can be best understood by considering the latest in this 'ratchet game' viz., the *Optical thermal ratchet*. This is probably the most elegant of such devices produced so far. This system was developed last year by Faucheux and his collaborators. In this experiment a plastic sphere of about 1.5 micron diameter, immersed in water, is illuminated by a circularly polarised infrared laser beam. The laser beam rapidly traces a circle in space. The electric field of the laser beam induces at every instant an electric dipole on the plastic sphere. This dipole in turn is attracted to the region of high electric field i.e. light intensity. It may be recalled that the very same mechanism is responsible for the attraction of paper bits by a comb, soon after brushing hairs. Thus the sphere will always be driven to the region of high optical intensity. In the process, the sphere will be confined to remain in the circle. However it need not stay at one place on this circle but can thermally diffuse from one point on it to another. If the incident beam is modulated by a chopper so that the light intensity gets modulated as a saw tooth wave, then all round the circle the intensity

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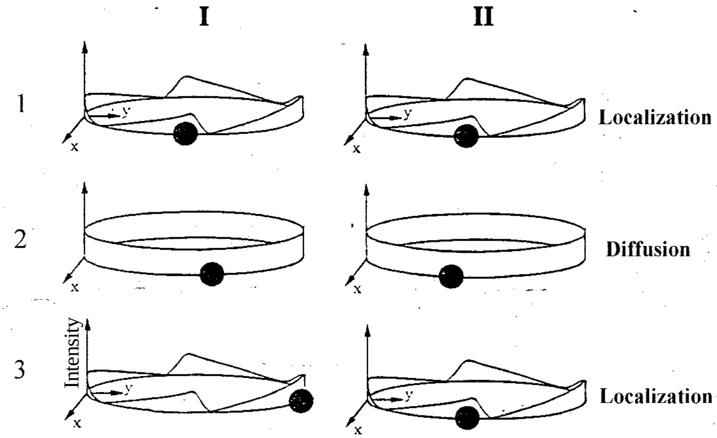
varies like a saw-tooth wave. The fact that the light intensity is modulated will force the sphere to always move towards the most intensely illuminated region of the circle. That is, it will move towards the position of peak intensity and get trapped there. When the chopper is off i.e., modulation disappears, the sphere can randomly diffuse away from the position of the peak intensity where it had been trapped. Let us say that the sphere diffuses past what was earlier a steep drop-off. Then it will move forward up the gentle slope to the next peak when the chopper is turned on. Instead, let us say it diffuses in the opposite direction. Then it will return to its original position when the chopper is on. Now the light modulation is such that every saw tooth is turned the same way. Thus, when the modulated light is continuously turned on and off rapidly, we periodically create, a saw-tooth modulation in an otherwise uniformly bright circle. Hence the particle can be made to migrate in one direction only, up the gentle slope. It is important to mention here that very similar ratchet mechanisms have been suggested in the case of molecular motors like kinesins used in the transport of vesicles in cells.

Optical Ratchet

1 A plastic sphere in an optical trap at the peak intensity of a saw-tooth profile.
2 When modulations are absent we get random drift, due to Brownian motion, to the right (I) or left (II).
3 Reappearance of the saw-tooth profile either pushes the sphere forward (I) or returns it to the same peak (II).



We can suggest in a lighter vein (with apologies to mathematicians) an interesting solution to the problem of a drunkard's walk in one dimension (See *Resonance* July 1996). Though the drunkard will reach his house eventually, he will take an unduly long time. We can speed up his homecoming. Let us say that the path from the bar to the drunkard's house is paved with identical planks all of them hinged at the ends facing the house. The other end of each plank which is facing the bar can be raised to a pre-determined height. Therefore, when all the planks are raised at the ends facing the bar, we find the path to be in the nature of periodic gentle slopes like the roof top of a workshop. Periodic raising and lowering of these planks while the drunkard is walking is exactly like the previously discussed case. Except that, here he gets trapped in a valley instead of a peak. Therefore by periodic raising and lowering of the planks we will be forcing the drunkard to go in the direction of his house!

Suggested Reading

- **R P Feynman, R B Leighton and M Sands. *Feynman Lectures on Physics*, Vol.1.Chapter 6. Addison Wesley, 1963.**
- **J Rousselet et al. *Nature*. Vol.370.p.446, 1994.**
- **L P Faucheux et al. *Phys. Rev. Letts*. Vol.74, p.1504, 1995.**

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