Annual bird migration is a beautiful yet mysterious phenomenon. Hundreds of species of birds migrate long distances with great precision every year. Some of them even spend six to eight months a year in flight. Despite several attempts to understand the underlying biophysical mechanism, it has been one of the least understood natural phenomena till date.

The magnetic field of the Earth helps many organisms (e.g. sea turtles, sharks, etc.) navigate large distances. It turns out that migratory birds also use geomagnetic field for navigation, albeit in a complex way. That is why this phenomenon is also termed as avian magnetoreception and the migratory birds are said to possess a ‘compass’.

In order to better understand the phenomenon of avian magnetoreception, behavioural experiments have been performed where a migratory bird is captured and kept in a big wooden chamber. During the migratory season, the bird develops ‘migration anxiety’ where it instinctively tries to fly. During this ‘compulsive’ flight, the characteristics of the birds’ migration are studied by artificially manipulating the magnetic field in the chamber and observing the bird’s flight behaviour. Following characteristics have been observed in these behavioural experiments:

- **Light activation:** The birds require the presence of light above certain frequency to be able to sense the geomagnetic field. Several experiments have shown that the avian compass works from UV light to green light and gets disoriented in the presence of yellow and red lights.

- **Inclination only compass:** The migratory birds are not sensitive to the polarity of the magnetic field i.e. if the north pole and the south pole of the magnetic field are interchanged artificially, the birds are not able to distinguish the change. However, they are sensitive to the
in the triplet state, the recombination is impeded and the radicals again recombine to make the same products. However, if they are in the triplet state, the recombination is impeded and the radicals can make a different product — called the reaction product. Interestingly, the initial singlet state of the radical pair can change — under the influence of the geomagnetic field and the interaction with nearby nuclei — to the triplet state and back. Therefore, the amount of reaction product depends on the fraction of radical pairs in triplet state that, in turn, depends on the local geomagnetic field and nearby nuclei. Therefore, in principle, the amount of final product yield of this reaction contains the information about the local geomagnetic field which can be used by the bird’s brain to get navigational information.

This is what goes on in the visual system of the bird. It becomes even more interesting that the spin state of the radical pair stays in a coherent superposition of multiple states and the spin state evolution is governed by the laws of quantum mechanics. Therefore, a macroscopic system like ‘avian compass’ of the birds operating at room temperature has indispensable quantum mechanical principles going on at its core.

A suspicion about the radical pair mechanism arises as the strength of the geomagnetic field (on energy scale) is very small as compared to the thermal energy at room temperature. But this entire mechanism is operating in transient where non-equilibrium conditions prevail and even a small intervention by the geomagnetic field can change the course of the reaction in a significant way. This has now been validated by several experiments as well.

This entire mechanism becomes even more intriguing as another domain of science intervenes here i.e. Chiral-Induced Spin Selectivity (CISS). Chirality in molecules implies that the molecule is non-superimposable on its mirror image by translation or rotation operations. Chiral molecules have the same chemical composition but different geometric configurations. Chiral molecules can have two distinct kinds of configurations characterised by the direction of polarisation of light produced by these kinds of molecules. CISS is a seemingly unrelated effect from physical chemistry whereby the electron transport across chiral molecules is spin selective i.e. one spin is preferred in one type of chiral molecules and the opposite spin is preferred in the other type.

Almost all protein molecules are chiral. In fact, most of the biomolecules are chiral in nature. It turns out that chirality helps radical pair spin dynamics retain quantum superposition (coherence) of spin states in radicals. It is a non-trivial phenomenon as quantum coherence and chirality are seemingly unrelated effects. Moreover, chirality augments the sensitivity of the avian compass significantly. This is still an ongoing area of research and more experiments and extensive theoretical analysis are required to understand the physics behind the navigation mechanism in avian migration.

It seems that nature is more proficient in harnessing the potential of quantum mechanics than human beings have done so far. Possibly that is due to fine tuning of biophysical processes over millions of years of evolution. In order to comprehensively understand a natural process, one needs expertise in multiple disciplines of science and engineering. Therefore, for an aspiring scientist, it is indispensable to have a good grasp of mathematics and an acumen to connect multiple disciplines of science.

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