Chapter 5

DELIGHTS OF TRANSPORT
How the cell’s contents are moved around

In chapter 4 we introduced metabolism, the chains of chemical reactions that take place inside living cells. We emphasised the close reciprocal dependence between metabolism and cell structure. Now we turn to another major aspect of cell activity: transport. How are a cell’s ingredients imported, exported and moved from place to place, and how are its internal structures kept in position? And how do cells move?

A variety of transport mechanisms
The contents of a eukaryotic cell range from the tiny molecules of metabolism to large internal membrane structures. A protein molecule is around ten times longer than a metabolite molecule. A molecule of RNA is hundreds of times longer than a protein. A mitochondrion is three or four times longer still, and a great deal fatter than an RNA molecule. Cargoes of such widely different sizes are unlikely to be moved efficiently by a single mode of transport. Therefore, the cell has a variety of transport mechanisms.

The main ingredient of a cell is water. An average-sized human cell contains up to 1,000,000,000,000,000 (i.e. $10^{15}$) water molecules. Picture a small lake fed by fast-flowing streams and drained by a large river; the level of water in the lake remains practically constant, and underwater currents flow, but no individual water molecule stays in the lake for long. The flux of water in a cell behaves similarly; water enters and leaves all the time and currents flow, but the amount inside the cell scarcely changes. But in a cell, unlike a lake, the “feeder streams” and “outflows” are dispersed all over the surface. Water flows continually in both directions across almost the whole of the cell membrane. Similarly, it enters and leaves each of the membranous inclusions - nucleus, mitochondria, lysosomes and so on.
Within the cytoplasm (the part of the cell outside the nucleus), water flows first one way and then another, or round in circles. These movements are generated in various ways: by activities of the cytoskeleton, transport of metabolites across membranes, and metabolic production and utilisation of water. (Remember that water is a product of catabolism\(^9\)).

In chapter 4, we saw that metabolic pathways are efficient because the enzymes are fixed in ordered sequences on membranes and metabolons. Their efficiency is further enhanced by the flow of water inside the cell, which continuously feeds raw materials to the enzymes and removes the products. (Most nutrients and metabolic intermediates are soluble in water.) The principle is familiar to chemical engineers: making the reactants flow over a catalytic bed ensures that the product is made quickly and in high yield. Living cells discovered how to put this principle into practice more than a thousand million years before chemical engineers existed.

The cytoplasm is not a simple liquid, even if we discount the cytoskeleton and all the internal membrane structures. If - to revert to the box model of chapter 3 - the half-kilo of salt representing the cell's proteins had been mixed with the other solid ingredients and the appropriate volume of water (5 litres), a runny paste would have resulted. Salt is not protein but the effect is similar. Proteins are sticky molecules; they adsorb water and they adhere to each other. So the cytoplasm, minus membranes and cytoskeleton, can be pictured as a runny paste. Examined under a high-voltage electron microscope it is a loose network of thin strands, mainly water-saturated proteins. However, cytoplasm is not a stable gel like a table jelly. The strands are continually breaking and reforming; those in a table jelly are much less labile.

Water, and the small metabolite molecules dissolved in it, flow through the cytoplasm fairly easily and quickly. Bigger molecules are a different matter. They repeatedly become entangled in the network, and however quickly the strands of the network break and reform, this slows their movement. For protein and RNA molecules, which tend to stick to the network and become part of it, the slowing is potentially dramatic. They could be almost immobilised unless a path could be cleared for them.

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\(^9\) A simple calculation can be made, based on the amount of oxygen your body takes up per unit time while you are at rest (sitting in a chair reading this book, for example). If we assume that nearly all the oxygen you breathe in is converted to water by catabolism in the mitochondria; your body contains ten million million cells; and an average cell contains a hundred mitochondria… then ten thousand water molecules are produced in each mitochondrion every second. If you exert yourself, then you take in oxygen more rapidly and the rate of water production increases.