Basics of the cell

Introducing the cell

The cell is the smallest unit of life. Some simple organisms are unicellular, consisting of just one cell, whereas more complex beasts – like us! – are multicellular and have vast numbers of them.

Humans are among the organisms built up from eukaryotic cells, which have their DNA packaged up into a nucleus, and lots of subcellular compartments, called organelles. Prokaryotic organisms (such as bacteria) are simpler. These cells still have DNA, which exists as a non-membrane-bound plasmid instead of within a nucleus. The vast majority of these are unicellular, whereas most eukaryotic organisms are multicellular.

The intricately organised cytoplasm of the eukaryotic cells allows them to have different things happening in different compartments. Keeping a cell going depends on getting the right molecules to the right place at the right time. Having distinct spaces does half the job, but it also requires sophisticated machinery to ensure the right things get into each section. Only material the cell has finished with, for example, can be allowed into lysosomes, where powerful enzymes are poised to break down the material into smaller molecules.

Cell theory was put forward in the 1830s, soon after the cell nucleus was first identified in eukaryotes. It recognised that living things are made of cells, that cells are the basic units of life, and that new cells are created by old ones dividing into two. Viruses – simple particles of genes and protein – need to get into a cell and hijack its cytoplasmic machinery to copy themselves. We describe these as acellular, and they are not considered to be living because they can't reproduce in the absence of a host cell.

Mind your membranes

The cell membrane is an essential part of the cell. It separates the inside and outside of the cell, essentially defining its boundary.

First, the cell membrane is a barrier. Because it is semi-permeable, the membrane prevents large molecules diffusing into the cell unless the correct transport proteins are present. This allows the cell to control what goes in or out. Second, the membrane plays a part in signalling and signal recognition. Many membrane-associated proteins (integral or peripheral membrane proteins) are involved in signalling with neighbouring cells or in detecting and relaying signals from outside of the cell.

What makes a membrane?

The basis of the membrane is the phospholipid bilayer, which comprises a double layer of phospholipids. Phospholipids are made up of a phosphate-containing 'head' region and two fatty acid 'tails'. The polar heads are hydrophilic ('water-loving') and the non-polar tails are hydrophobic ('water-hating') – this causes the phospholipid tails to orient away from the water-containing cytoplasm and extracellular matrix, forming a double layer of phospholipids.

This basic semi-permeable membrane is studded with other components, including proteins and cholesterol. Membrane-associated proteins can be bound to sugar chains (glycoproteins) and are often involved in signal recognition. Cholesterol molecules act as 'spacing' molecules between phospholipids to maintain fluidity and stability.

This is especially important with fluctuating temperatures – when hot, the membrane becomes more fluid and cholesterol stabilises the membrane. When cold, the fluidity in the membrane decreases, so cholesterol can separate the phospholipids out to enforce fluidity.

But how does this structure allow molecules to pass in and out of the cell? Hydrophobic, non-polar molecules (including oxygen, carbon dioxide and steroids) can diffuse freely through the membrane because the phospholipid ‘tails’ create a hydrophobic core. The passage of any other molecule is governed by its charge and size.

Small, polar molecules (including water and glycerol) can pass through the membrane. Larger polar molecules (including the sugars glucose and sucrose) and ions (including sodium ions/Na^+ and potassium ions/K^+) are unable to pass through the membrane directly. These molecules rely on transport proteins embedded in the membrane to be moved across the membrane.

On the move

There are three ways in which a molecule can cross the membrane. Small, polar, hydrophobic molecules that are able to pass directly through the membrane do so by passive simple diffusion – they only need a concentration gradient to move across the membrane.

Larger molecules crossing the membrane down a concentration gradient do so by passive facilitated diffusion. This requires either a channel or a carrier protein, which both allow specific molecules to cross the membrane. Because the molecules are travelling down their concentration gradient, no energy is required for this transport. Channel proteins act like a pore to let their specific target molecule cross the membrane.

Carrier proteins act a bit differently. On the extracellular side, they bind their target molecule, and this binding causes the carrier protein to change shape and allow the target molecule to move into the cell. Both these transport proteins can either always be working or be ‘gated’, meaning they are only allowed to work at certain times. For example, they might only be turned on when the cell needs to import a specific molecule.

The third type of transport is active transport – where large or charged molecules cross the membrane against their concentration gradient. This process requires energy, in the form of ATP made through respiration. One of the most important examples of active transport in the cell is the sodium ion/potassium ion – Na^+/K^+ – pump (sometimes called the Na^+/K^+ ATPase), which moves two potassium ions (K^+) into the cell for each three sodium ions (Na^+) it moves out. This maintains the electrochemical gradient of these ions. Its ‘pumping’ process is somewhat similar to the carrier proteins. First, the intracellular face picks up three sodium ions, then the pump hydrolyses ATP to release energy to power the next step. The pump then undergoes a conformational change – where the pump’s structure changes so the sodium ions are facing the extracellular matrix. These sodium ions are released, and the pump picks up two potassium ions and again changes in shape to let the potassium ions move into the cell.

Inside the cell

How do things get around in the cell?

The inside of the cell is a scene of constant motion. Soluble molecules move around apparently randomly in the cytoplasm (because of random Brownian motion), but other components are transported more precisely. Many proteins are only allowed into one of the cellular compartments. Cells also have an elaborate network of fine protein filaments (strands), an interior cytoskeleton, which helps them keep their shape and provides the rails of a transport system.

Small protein motors pull vesicles, full of cell products, up or down microtubules or actin filaments. Special labels ensure the right cargo is sent to the right destination. These are usually proteins, or parts of proteins, sticking out of the vesicle.

The same system also moves organelles around or anchors them in place. The cell uses a lot of energy for all this transport, but it needs to speed things along. A protein molecule might take years to travel the length of the longest neuron (or nerve cells) (the sciatic nerve in your leg) by simple diffusion, but if it is bagged up and dragged along a microtubule it can cover 10 cm in a day. This is vastly more than most distances within cells, and means that even the ends of the long, drawn-out extensions of nerve cells, the axons, in your fingers or toes can be reached in a few days.