Why Icebergs Float

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Published by University College London

Morris, Andrew.
University College London, 2016.
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The mitochondrion had hit the news. What on earth was this unfamiliar part of the body? Was it one of those bits whose name we struggled to memorise for biology exams long ago? Who would have thought that such a remote word would become a public sensation overnight? The cause of this rapid rise to fame was the discovery in 2014 that a healthy embryo could be created for women with a terrible genetic condition if the cells of three people were used rather than the usual two. The lurid headlines played on the emotional consequences of ‘three-parent children’ and the potential legal ramifications. The story beneath the headlines provided the trigger for a fascinating exploration of how the body uses energy – a story crossing the boundaries of chemistry, biology and physics (not to mention nutrition, genetics, embryology and more).

Helen asked the first and most fundamental question: ‘What exactly do the mitochondria do?’ It is indeed one of those little bits you probably had to learn about in biology lessons. It is also possible that you have forgotten what you learned at the time. Mitochondria are one of the very small pieces of apparatus that float around inside a cell. Cells are small (ranging in size from one-tenth to one-hundredth of a millimetre), but like most biological structures they are themselves made up of parts. The most amazing thing about the cells in our bodies is that they all have the same basic structure, whether they form muscles, nerves, skin or bones. They have flexible walls (known as membranes) that separate their watery internal contents from the watery external world. The membrane consists of two parallel layers of long, thin molecules called phospholipids. Each molecule has one end that mixes easily with water and another end which is oily and does not. The diagram shows a section of membrane (Fig. 15.1). The long lipid molecules lie next to each other in two layers. The molecules are orientated so that the ends which mix with water (shown as red in the diagram) are on both
the outer and the inner surfaces of the cell (the upper and lower parts of the diagram), while the middle part of the membrane is essentially oil-loving. This enables the membrane to tolerate the watery environments both inside and outside the cell, while repelling water within itself. It makes the cell watertight.

This compartmentalisation of cells – separating the inside from the outside – is essential to enable cells to carry out their roles. Cells need to do various kinds of things, such as storing insulin or carrying around oxygen, and they need to be self-contained. The cellular structure also reflects the way in which the organisms grow and develop over time, by multiplication of this basic repeatable unit. In contrast to manmade compartments such as prison cells or gym lockers, designed to isolate their contents completely, biological cells are able to admit substances in and out through their membranes. This is how they survive over the long term, by allowing the materials they need to pass through and by expelling those they don’t require as waste. In this way small molecules vital to life, such as hormones and energy-rich compounds, are able to get inside cells and produce their beneficial effects.

Inside the cell membrane are several pieces of apparatus – known collectively as organelles. One of these, the nucleus, stores genetic information in the giant DNA molecule. Another, called the ribosome, enables information from the DNA to be transcribed into the various
building materials and tools the body needs, in the shape of various kinds of protein. However, the particular organelles involved in the so-called ‘three-parent baby’ story are less well-known ones: mitochondria. They are rather like miniature cells within a cell, surrounded by little membranes of their own. Their special role is to convert energy that is released when molecules from the food we eat combine with molecules from the oxygen we breathe in. Mitochondria make this energy available for use in the cell. They do this by transferring the energy through a series of chemical reactions to specialised molecules, which then carry the energy to where it’s needed. These molecules, known by the simple acronym ATP (an abbreviation for Adenosine Tri – Phosphate), supply the energy needed for activity in the muscles, the brain and other parts of the body.

‘Can we pause a moment here, Andrew? I don’t think I’m the only one who is unsure about what energy actually is. I know we’ve talked about it before but can you remind us?’ This plaintive cry came from Stephanie, a psychotherapist who had in fact studied science at ‘A’ level many years ago. It was a good question at the time and gives an excuse to remind ourselves of what was said in chapter 13.

Energy is essentially an abstract concept, not something substantive. In physics it’s defined as ‘the capacity to do work’, which means that when a system changes from a higher to a lower state of energy things happen, work gets done. Energy keeps circulating round, changing its form but remaining unaltered in overall quantity.

The energy stored in chemicals is released when the atoms are rearranged during chemical reactions. The amount of energy released in this way can be measured. In fact you routinely hear about this in connection with the number of calories in foods. A calorie is simply a measure of energy (an old-fashioned one, in fact). The Calorie with a capital C is used for foods to denote 1,000 calories as the latter is an inconveniently small unit. When a pot of yogurt is labelled as having 120 Calories per 100g, it shows the total amount of energy released in this way for every 100 grams of the yogurt (roughly half a typical pot). After consumption the molecules in our food – the various proteins, fats, sugars and so on – are broken down in the digestive system into a limited number of basic molecules, mainly a type of sugar molecule known as glucose. The molecules of glucose are absorbed into the bloodstream from the small intestine. This glucose passes into the various cells of the body and on into the mitochondria inside each cell. Here energy is released when the molecules of glucose combine with oxygen.
Of course the amounts of energy involved in all these activities are absolutely microscopic compared to the energy used in boiling a kettle or driving a motor car. A teaspoon of yogurt may contain roughly 10 Calories or 42,000 joules of energy (the standard unit of energy). The amount of energy released when a single ATP molecule acts on a muscle is miniscule, about 0.000000000000000000000051 joules. The energy economy of a human body consists of zillions of miniscule transactions taking place every time a muscle quivers or your skin cools down a fraction. Each involves just millionths of billionths of billionths of joules of energy. Added together, the total energy used every second by all the chemical reactions in your body approximates to a single 60 watt light bulb. That means it's using up 60 joules of energy every hour. So humans are quite low-energy beings really, but of course highly efficient in the way they use it.

It's at a point such as this that a discussion group begins to realise that the various twists and turns of its conversation, interesting though they may be, have taken it a long way from the original issue. Someone often interrupts to remind the group of its starting point. On this occasion the task fell to Helen. ‘Andrew, it's all very fascinating, this story of how energy is used in our bodies, but what's it got to do with the “three-parent babies” we were talking about in the beginning?’ she asked.

In fact it has lot to do with it, especially for the children suffering from mitochondrial disorders, and for their parents. Put bluntly, if the mitochondria don’t work properly all the energy-consuming systems of your body are at risk: that means loss of muscle coordination, damage to hearing and sight, liver and kidney disease, as well as a host of other symptoms. Until recently there was no cure for this condition. The problem is that mitochondria uniquely depend on their very own supply of mitochondrial DNA to function. The other parts of a cell use the main stock of DNA that is wrapped up and stored in the nucleus, a different organelle within a cell. The amount of DNA in the mitochondria is, however, minute in comparison to that in the nucleus. In rare cases the DNA in the mother’s mitochondria are defective; this will be passed on to her children, whose mitochondria will then have the same problem. It is an inherited genetic defect, passed through the mother. In the new procedure, first tested in 2014, the egg to be used to create an embryo is taken not from the biological mother, but from a donor whose mitochondria are healthy. In order that the embryo's DNA comes from the biological mother, however, the nucleus of the donated egg cell – with its third-party DNA – is first removed, and the nucleus of the biological mother’s egg is then inserted into the donor cell in its place. It is
this that contains the vital DNA that will determine the characteristics of the new baby. The new hybrid cell contains the mother’s DNA inside a healthy donated cell. It is this that is then fertilised by the biological father.

Sally was keen to pick up on an earlier point about energy in the body. ‘You say that the energy stored in molecules is released when the atoms that make up the molecules get rearranged in a reaction. How does this work?’ This intriguing question may have arisen in the context of the body, but it opens up a fundamental idea about energy that applies in all its contexts, whether biological or physical.

Systems in general tend to shift spontaneously from a position of high energy to a lower one, but not the other way round. For example, streams at the top of a mountain will flow spontaneously down to lower ground – from a higher to a lower level of gravitational energy; they won’t flow uphill spontaneously. Similarly a battery will drive a mobile phone for a while, as the chemicals in it gradually react, shifting from a higher to a lower state of energy. In the right circumstances, however, energy can be held in a higher state instead of flowing spontaneously; it is then ready to be released when needed. This is what a hydroelectric dam does up a mountain, holding the water at a higher energy level until the energy is required. It’s also what a battery does when the device that contains it is switched off, storing its energy until the device is switched on again.

Of course, energy that is stored in these ways has to be put there in the first place by some means. A mountain dam reservoir is fed by streams falling from even higher energy levels. A battery has to be recharged from the mains (or replaced). The same happens for food acting as a store of energy. The molecules that make up our food come from plants that acquired their energy from chemical reactions powered by the Sun while they were growing. In the process high energy molecules were created, mainly carbohydrates, fats and proteins. It’s the energy from the Sun that was used in the first place to forge the high energy arrangement of atoms in these food molecules.

The remarkable virtue of the notion of energy is that the self-same concepts about it apply in every conceivable context. From the human body to the interior of stars, from electrical supply to the growth of plants, we can imagine energy being stored, transformed and released in an infinite variety of physical processes. This is indeed an act of imagination, given that energy is not a tangible substance. It is one of the great abstractions, a measurable quantity we can never visualise, but whose endless transformations we can account for in the most minute detail – from the
tiny fraction of one joule of energy each time a mitochondrion powers up an ATP molecule to the 10,000,000,000,000,000,000,000,000,000,000 joules produced each day by the Sun. We owe a lot to the brilliant engineers and scientists from the age of steam who developed the modern concept of energy so fundamental in today’s world.

Another form of energy, one that for many people is as mysterious as it is helpful, is electrical energy. Electricity is invisible, silent and essential for almost everything we do. It’s so powerful that it can kill in a flash, and so responsive it senses the flick of a finger on a screen. In chapter 16 some of the basic concepts in electricity are explained as they cropped up in one, rather exhausting, discussion.