Why Icebergs Float

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'OK, but what was there before all the atoms and molecules?' We were talking about the origins of the universe in a wine bar, as you do. We had been working our way backwards from the universe we know about today, with its stars and planets, meteorites and asteroids, towards its earliest moments, just after the Big Bang. You start thinking about how atoms came into existence in the first place – have they always been there? Then you go back even further. What about the particles that make up atoms – the protons, neutrons and electrons – how did they arise? Continuing on, you get back to what we now see as the fundamental components of matter – the quarks that go to make up protons and neutrons. In each of these stages one form of matter aggregates together to form the next, from quark to proton and neutron to atom. Yet this wasn't really the issue. Our questioner had accepted this account of the way the material universe had evolved and was now addressing an even more challenging concept. There must have been an even earlier stage before stuff of any kind existed – atom, proton or quark. What was there before matter?

This is a profound question, demanding imagery that is more or less impossible to summon up, but in scientific terms the answer is really quite simple to state – there was just pure energy in the time before the matter that makes up today’s universe came into existence. Fair enough, we might say: energy, we’ve heard of that – at least the universe was kicked off by something familiar, not some strange, incomprehensible thing. Energy is something we know about; we use it every day, our lives depend on it, we even receive a bill for it every quarter! But is energy really such a familiar concept? Do we understand its meaning in any depth? To quote from the inevitable question raised in the wine bar discussion: ‘What actually is energy?’
Connotations

This simple question, thrown up by thoughts about the universe, led into deep and unpredictable discussion about some very down-to-earth aspects of our daily lives, from boiling milk to keeping fit. Simple though the question is to pose, working out what it means is not so easy – which is strange for a word that features so often in everyday conversation.

‘It’s something that can be felt but is intangible – like the heat of the Sun,’ suggested Celia, always good at finding a link to everyday experience. ‘Isn’t it a force of some kind?’ ventured Rosie, trying another tack. ‘It’s to do with physical fitness and wellbeing, surely – whatever it is you never seem to have enough of it,’ Jean claimed wryly. This observation led on to a further everyday association: the energy in food. Calories are a big talking point today as many people struggle to control their diet and regulate their weight. If you have the patience (and eyesight) to read the small print on many food labels you’ll see the word ‘energy’, setting out how many calories are to be found in every 100 grams of the food.

Of course, it’s not only physical things, such as sunshine and food, that the word brings to mind. Another area of meaning is summed up by a comment from Michelle: ‘It’s when you feel something about somebody – an intuition. People give out positive or negative energy vibes.’ This more spiritual association leads on to the cultural context in which the word is used: as Sonya put it, ‘Do we mean a Western definition? In my country of origin it’s common to talk of energy in this way.’ Indeed in traditional Chinese medicine the concept of ‘chi’, which is considered to flow through the body along channels known as meridians, is routinely translated as ‘energy’. The word energy is understood in many different ways – it all depends on the context in which it is used. It was not until the mid-nineteenth century that the word was commandeered for its specific role in science. Originally a Greek word associated with activity, ‘energy’ came to be used to denote power or vigour in, for example, action and speech. It is not unusual for everyday words with a range of meanings to be adopted in science to denote something specific. This plundering can lead to confusion, if scientists take for granted the meanings they have been trained to adopt, while everyone else understands the terms in their vernacular sense.
Energy is commonly defined in science as ‘the capacity to do work’. This is routinely taught in schools, but it is not obvious what it truly implies. Let’s take the opportunity to look more closely at the phrase. The word ‘capacity’ itself has many connotations: the maximum something can contain or the ability to do something, for example. It’s the latter meaning that is behind the concept of energy. It suggests that energy is not a substance, nor any kind of tangible or visible thing. Instead the word describes something abstract: the potential to do something. Thus a closed jack-in-the-box has the potential to spring open, a sugary drink the potential to fire up your muscles, a poised hammer the potential to drive in a nail. In each case, this abstraction – energy – seems to get stored up in some kind of physical system. A useful analogy is with money, also an important but abstract entity. Normally nowadays money has no substantive physical presence, but is merely represented by figures on a statement or words on a bank note – yet it has the capacity to do an awful lot for us when released!

The other part of the definition is about ‘doing work’. This tells us about what happens when the ‘capacity to do something’ is actually realised. When energy is released, the textbooks tell us it is ‘able to do work’. But is this strictly correct explanation really helpful? As so often happens in learning science, one definition simply pitchforks you into a further one; self-referring cycles of definition can seem as maddening as a drawing by Max Escher.

‘Work’ can be explained fairly simply because the scientific meaning is not too far removed from the everyday one. Work is done when a force is applied to something as it moves. So, for example, when your legs push bicycle pedals against the friction of the tyres on the road, they are doing work. The energy you have in your legs has the capacity to do work against friction. Examples abound, in trains and planes, machines and muscles – forces are moving things everywhere.

The word energy was first used in a scientific context in 1807 by the English investigator Thomas Young, and was given its modern scientific meaning by William Thomson (later known as Lord Kelvin) in 1852. Yet in an 1847 lecture, even the leading physicist (and brewer) James Joule still employed the more archaic phrase ‘living force’ (vis viva) to describe what we now call energy. These men were living in an age of unprecedented growth in manufacturing and industrial processes.
generally. New ideas and inventions abounded: science and engineering were proving not just interesting concepts, but vital elements of industrial growth. In fact scientific understanding of what we now call energy developed hand in hand with economic development. It was not so much disinterested scientists, dwelling philosophically on the concept of energy and its various transformations, who stimulated experiment and theory; progress was rather driven by the owners of mines and railways, anxious to increase the efficiency of their steam engines. The realisation that heat generated by a coal fire could result in movement of a heavy locomotive or pump led to investigations of the link between heat and mechanical movement. The older concept of heat as a kind of fluid inside materials (dubbed ‘caloric’) was abandoned in favour of the concept of it as energy – something that could change its form, as heat was converted into mechanical movement, but whose total amount was always conserved.

‘Ah’, interrupted Mary at this point. ‘“Energy is neither created nor destroyed” – I remember learning that at school. So that’s what it meant!’ She was right: the chemical energy released when coal combines with oxygen in the burning process reappears as energy in the form of heat. This in turn creates the steam that drives a piston, whose motion converts the energy into a mechanical form. When all the energy is accounted for, whether it resides in the motion of the locomotive or is lost as heat to the surrounding air or in the frictional rubbing of machine parts, the total sum remains the same as the amount that was released in the original combustion of coal with oxygen. Although today this concept of the ‘conservation of energy’ seems straightforward and almost self-evident, it was not arrived at through abstract reasoning but through meticulous measurements conducted in carefully controlled laboratory experiments in the mid-nineteenth century.

The concept of energy as a kind of interchangeable currency rather than a physical substance was a major step forward, and one that seemed counterintuitive at the time. We might well wonder what happens if we get up from a chair, eat some food, go for a run and end up back in the chair we started from – was energy really conserved? It seems to have just gone, dissipated. It is only when all the heat energy that we have given up to the surrounding air, as we run and digest, is taken into account that the total sum expended is seen to balance the energy consumed.

Talking of food reminds us of one of the commonest references to energy in our daily lives: the way it appears on food labels. What does it mean, what is a kcal? We are well aware that food contains
energy – after all, we talk of needing an energy burst from glucose when we are exhausted. Yet where is the energy in a chocolate bar? How is it stored and how does it get released into our bodies? Even more perplexing, how on earth is this linked to the energy in steam locomotives and electricity supplies?

Unrelated though these questions may sound, the answers reveal a surprising unity. Ultimately the energy expressed in each of these contexts has its origin in a similar place: the arrangement of atoms within molecules. Foods, plants, coal, oil – all these substances are composed of molecules made up of atoms. These molecules have been forged in chemical reactions during which the atoms of the combining molecules were re-arranged and locked together – rather as the character in a jack-in-the-box is pushed into the box and the lid latched. In other words energy gets stored up when things are pushed together against a resistance and then firmly locked together. The energy in food and fuels is associated with the way in which atoms hold together within molecules, much as the energy of a jack-in-the-box is associated with the compressed spring kept in place by the latched lid.

If we want to consider an even deeper level of explanation, we might ask where the energy came from to put the atoms together into a molecule in the first place. For our jack-in-the-box analogy, this would be the equivalent of the human energy that compressed the spring as the lid was closed in the first place. In the case of food, coal or oil the ultimate source of this energy isn’t to be found anywhere at all on Earth. As you might have guessed, it all derives from the Sun, the source that drives the chemical reactions in plants as they grow. Plants are harvested for food, grazed for meat and, millennia ago, became the raw material for the coal beds and oil fields that power our locomotives and generators today.

‘All very interesting’ was the general reaction as this explanation was unfolding in one discussion group, ‘but how do we get from the idea of the arrangement of atoms in molecules to the sensation of energy we experience in our bodies – or lack of it when we feel exhausted? How does the energy in a cheese sandwich or glass of beer work its way into our system and get us going?’ As we eat and drink, wonderful as the experience can be, all we are doing from a biological point of view is getting plenty of the right kind of molecules down into our digestive apparatus. There, assailed by enzymes in a bath of highly concentrated hydrochloric acid, these energy-laden molecules are gradually broken down into smaller ones capable of passing through the membranes that line our gut. Being made of
large molecules themselves, these gut membranes are quite capable of permitting the smaller molecules from our food to pass through and enter the blood vessels close by. Thus high energy molecules enter our bloodstream and, by this means, circulate throughout all parts of our bodies. Almost every cell of the body contains places (called mitochondria) where the energy contained in these nutrient molecules is transferred to a standard energy carrier that is then used throughout the body. The way in which this energy carrier, known as ATP, goes on to get you moving and thinking is discussed in chapter 15, Energy for Life. If you exert yourself, physically or mentally, without adequate nourishment, it’s no wonder that you feel exhausted. In a colloquial way, we complain of having no energy and, by and large, that’s just right: energy is indeed what we are short of.

**Conclusion**

Today the word energy has so many connotations in everyday life that our thoughts about it have ranged widely – over physical things such as forces and movement, biological aspects, for instance the food we eat, and also more personal things to do with our culture and beliefs about people and our bodies. Not surprisingly the scientific concept of energy appears rather narrowly defined in relation to these broader notions. Indeed it is; this is how science proceeds, by establishing a universal definition that enables measurements to be made and relationships to be quantified.

This more precise use of the word ‘energy’ has given rise to countless experiments and insights that have gradually extended use of the concept to previously disparate areas of knowledge: heat, mechanics, light, electricity and, more recently, nutrition and physiology. It is now central to our understanding of a host of contemporary global issues, from climate change and nuclear energy to feeding the hungry and combating disease.

In the next chapter we build on the concept of energy outlined here by considering what happens as energy moves around. It’s particularly relevant to our everyday lives when we consider the flow of heat energy through the walls and windows of our homes and the vital energy transformations that drive our ovens and refrigerators.