- Energy resources

SCIENCE

ENERGY EXPLAINED

It's one of the most basic concepts in physics, governing the behaviour of everything from subatomic particles to galaxies

WORDS ANDREW MAY

Energy is a word that crops up all of the time in countless contexts. Sometimes we think of it as a kind of resource or commodity, like water or light, but it isn't really a physical 'thing' like that at all. To a scientist, energy is an abstract property that's possessed by actual 'things' – water, light, human beings, spaceships, stars and anything else you care to think of. As such, it's one of the most important concepts in physics, and can help us understand how the universe works.

Energy manifests itself in amazingly diverse, constantly shifting forms and, perhaps for that reason, it took a long time for people to recognise its significance. It only really became an established part of physics in the 19th century, prior to which many great scientists were blissfully unaware of it. The turning point came when people started building machines like steam engines, which convert heat into motion, and needed to make them as efficient as possible. Though there's no obvious connection between the two, both heat and motion are forms of energy, and like all other kinds of energy, they're interchangeable.

One of the oldest definitions of energy is 'the ability to do work'. In this context, work often involves motion, and the energy associated with motion is called kinetic energy. A steam engine, for example, transforms heat energy into kinetic energy.

Did you know?
The Celsius scale used to be called centigrade

An important property of energy is that it can never be created or destroyed, only converted from one form into another. This 'conservation of energy', as it's called, was well established as an experimental principle by the 1850s. It was only in 1918, however, that German mathematician Emmy Noether showed that it arises naturally from the time-symmetry of the universe.

DID YOU KNOW? A gamma-ray burst can release as much energy in a few seconds as the Sun will produce in 10 billion years

DIFFERENT FORMS OF ENERGY

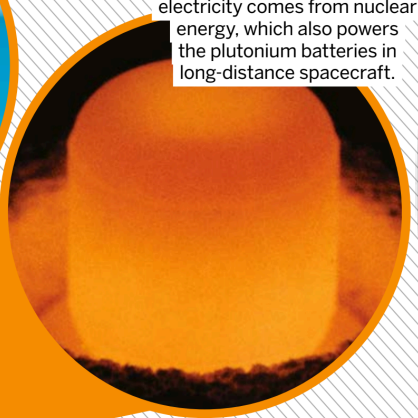
A few examples of the diverse ways in which energy can be stored or utilised



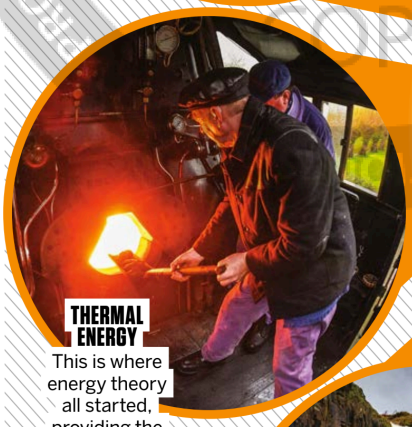
ELASTIC ENERGY
One of the earliest forms of energy to be exploited, elastic energy powers arrows fired from a bow.



ELECTROMAGNETIC ENERGY
We use electrical energy all the time; the most familiar way to store it is in a battery.



NUCLEAR ENERGY
Some of our household electricity comes from nuclear energy, which also powers the plutonium batteries in long-distance spacecraft.



THERMAL ENERGY
This is where energy theory all started, providing the heat needed to power steam engines.



CHEMICAL ENERGY
This is most people's favourite kind of energy, because it's stored in food!



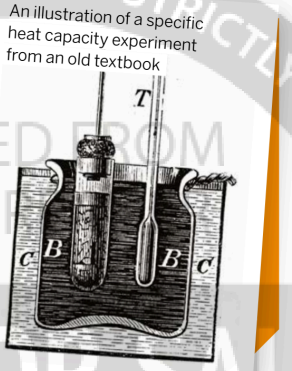
GRAVITATIONAL ENERGY
Anything that's raised above ground level has gravitational energy, which changes to kinetic energy when it falls.



KINETIC ENERGY
Energy is rarely stored in kinetic form, but we use kinetic energy all the time to get around.

HEAT AND TEMPERATURE

In everyday speech, heat and temperature are often used interchangeably, but in physics they're different things. Heat is a form of energy that, unsurprisingly, can be used to heat an object up. Like any other kind of energy, scientists measure heat in units called joules. But what happens when you pump heat energy into an object? At a microscopic level, you're making all the molecules inside it jiggle around more – in other words, you're increasing their kinetic energy. The object's temperature, usually measured in degrees Celsius, is an indication of how vigorously the molecules are moving about. But with different types of substances, different amounts of heat are needed to produce a given temperature increase. This is reflected in the substance's 'specific heat capacity', which is the amount of energy in joules required to raise the temperature of one kilogram of the substance by one degree Celsius.



An illustration of a specific heat capacity experiment from an old textbook

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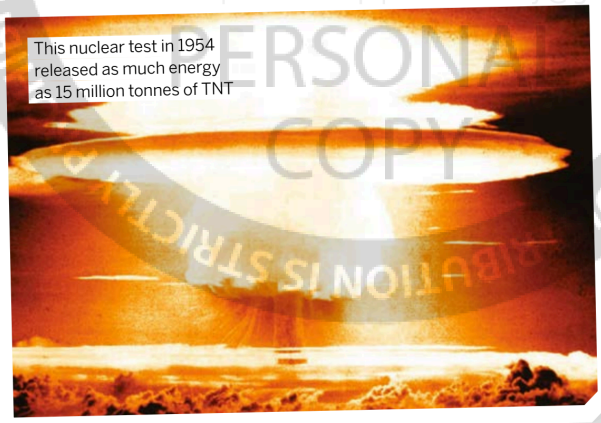
SCIENCE

CONDUCTORS AND INSULATORS

Some materials are better at transmitting different types of energy than others. This is perhaps most familiar in the case of electricity, where most know that metals like silver, gold, copper and brass are good conductors, while other materials such as plastic, rubber, glass and ceramics are good insulators. That's why most electrical cables are made from copper wire protected by plastic sheathing. There's an analogous situation when it comes to heat transmission. Again, metals are good conductors, while glass and plastic are insulators. But there are a few notable differences – such as diamond, which is an excellent conductor of heat but a good insulator of electricity. Water is a good thermal insulator, but while it's not the world's best conductor of electricity, it could be a fatal mistake to try using it as an electrical insulator.



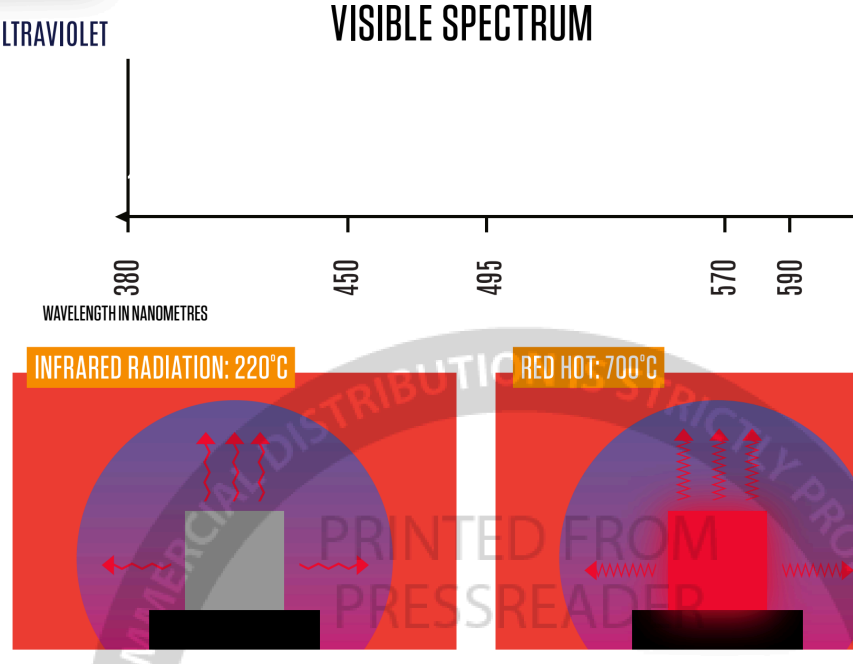
This nuclear test in 1954 released as much energy as 15 million tonnes of TNT



Some examples of materials that conduct or insulate against electricity and heat

THERMAL RADIATION

An object that is heated gives off infrared radiation. This is an electromagnetic wave like visible light, but at a longer wavelength we can't see. However, devices like thermal-imaging cameras can pick up this radiation and allow us to see warm objects in darkness or through smoke. The emitted radiation covers a range of wavelengths, being strongest at a wavelength that gets shorter as temperature increases. Eventually, the wavelength drops to a point where we can see the object glowing. At around 700 degrees Celsius, it becomes 'red hot' as it just creeps into the visible range. Then, at around 1,200 degrees, 'white hot' when it spans the whole visible spectrum. The theory behind this process was first developed for the simple case of an object that absorbs all the radiation falling on it – in other words, a completely black object – and for this reason it's still often called 'black body radiation'.



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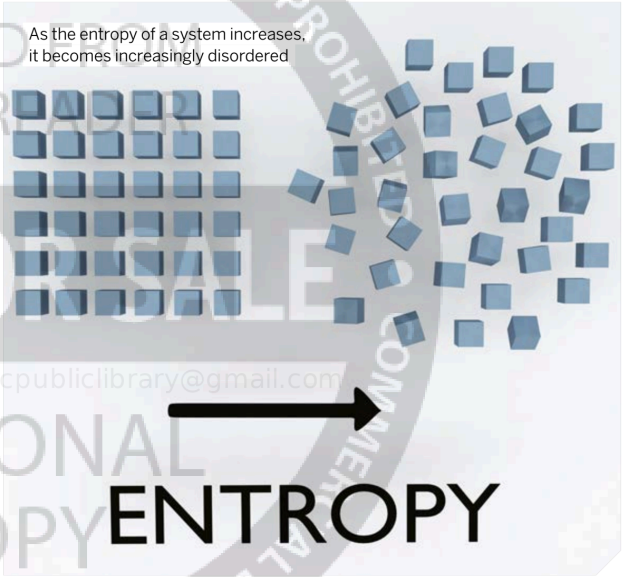
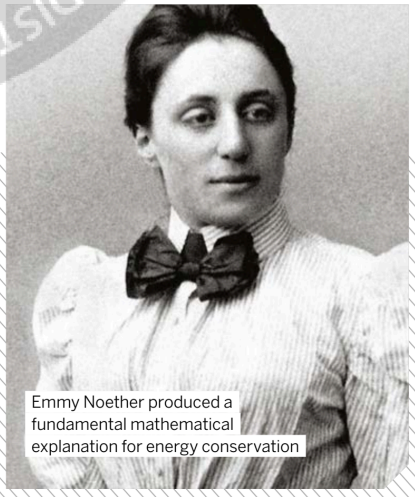
DID YOU KNOW? The principle that entropy can only ever increase is known as the second law of thermodynamics

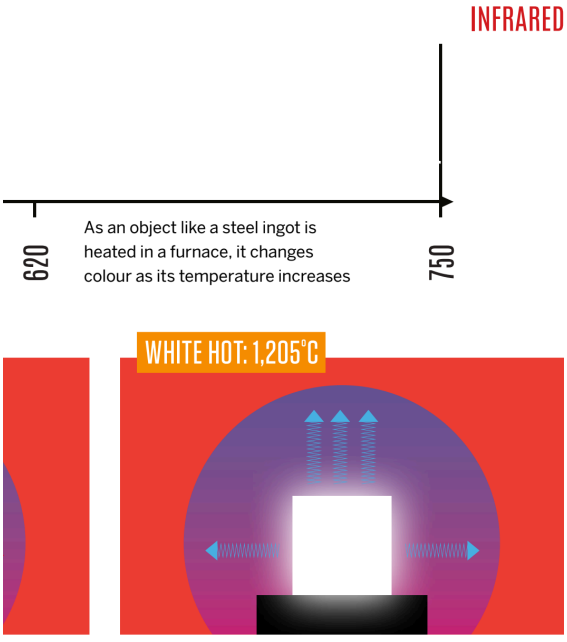
THE HEAT DEATH OF THE UNIVERSE

The conservation of energy means that the total energy content of the universe is an unchanging, absolute constant. But there's another physical property, called entropy, that does change. Entropy can be thought of as a measure of how much energy is no longer available to do useful work. As time goes on and the universe gets older, its total entropy gradually and inexorably gets bigger. In simplified terms, this means its energy content becomes more and more disordered. According to some theories, the universe will eventually reach a state of maximum entropy, after which nothing in it can ever change. This is referred to as 'the heat death of the universe'.



"Entropy is a measure of how much energy is no longer available to do useful work"


Emmy Noether produced a fundamental mathematical explanation for energy conservation




A wind farm converts the kinetic energy of wind into electrical energy

Did you know? The electromagnetic spectrum also covers X-rays

5 FACTS ABOUT ENERGY

1 KINETIC ENERGY WEAPON
Due to a shortage of explosives, some German V-2 missiles used concrete warheads during World War II, relying on kinetic energy alone for their destructive effect.

2 MOSQUITO POWER
The energy released by a pair of protons colliding inside CERN's Large Hadron Collider is comparable to the kinetic energy of a dozen mosquitoes.

3 LOTS OF UNITS
Besides joules, quantities of energy can also be measured in units of kilowatt-hours, calories, British thermal units, electron-volts or megatons, depending on the context.

4 NO FREE LUNCH
The conservation of energy, which is one of the best established principles of physics, is the main reason it's impossible to construct a perpetual motion machine.

5 A LONG WAIT
If you write down one followed by a hundred zeroes, that's the number of years before the earliest time the heat death of the universe could occur.

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