Getting energy out of knowledge

The exchange rate of pure information has been verified, reports s ananthanarayanan

EVERYBODY knows that knowledge is power and enterprises the world over invest billions in gathering information. But the word "information", as understood in physics, is related, of course, to the common perception and is precise in a different sense. In physics and in Information Technology, the unit of information that is called a binary digit or "bit" is the selection from a choice of two, like selecting "on" from "on or off".

By this measure, a sentence like "India is great", which has 14 characters, including spaces, is a selection from all the ways these 14 characters could have been written. We can see that each character could be one of 26 letters or a space – 27 in all. As each one could take 27 forms, the total number of forms the 14 characters could take is 14 multiplied by itself 27 times — 14^{27} – which is a number with at least 26 zeros, about a billion billion billion! The vast majority of the forms of the 14 characters, of course, would be nonsense and one could say the number, 14^{27}, is not a fair measure of the information that the three-word sentence conveys.

But the way the physical world works, with movement and processes, with billions of components continuously changing form, has been understood in terms of information exchange, just like this, and a precise relation of the equivalence between information and energy has been worked out. The actual energy that corresponds to a unit of information turns out to be very small indeed, and as of now it is not clear whether we could tap energy from information, like we get energy out of oil or atomic nuclei, and even verification of all the theory has not been possible.

The journal *Nature* reports that Shoichi Toyabe, Takahiro Sagawa, Masahito Ueda Eiro Muneyuki and Masaki Sano, all in Tokyo, have managed a remarkable "information to energy" conversion and have verified that theory, in fact, is right on!

The gas laws

Thinking about information and statistics began with trying to understand the behaviour of gases. To start with, it is clearly observed that the more the pressure, the less the volume; and the higher the temperature, the more the pressure as well as the volume, and so on. This feature of gases was neatly explained by the kinetic theory, which saw the gas as composed of exceedingly small and exceedingly numerous particles, the molecules, incessantly in motion, ricocheting off each other in collision.

Statistical calculations showed that for a given total energy of the gas, the speed of the molecules would distribute in such a way that a great majority were near about an "average", whose value changed as the gas was compressed, heated, cooled, etc. This soon led to the theory of simple gas machines, where a gas is heated, pressure increases, the gas under pressure drives a piston and cools down, is heated again, etc, and many practical applications were developed. This apart, it was seen that the distribution with the largest number of molecules at the "middle" value was, in fact, because it was at this energy level that there was, overwhelmingly, the most ways of distributing the molecules, keeping the total energy constant. We can see that to be in a state which has the most "equivalent" ways is to be rather "common" and nondescript, unlike the less likely distributions, which were less often seen precisely because they were "special" and "unlikely".

A number of things were understood while working with these gas cycles – one, that there was a "built in" limit to the efficiency of a gas engine; it just depended on the higher and lower temperature, the rest of the design had nothing to do. Another discovery, in working with the gas as consisting of molecules, was that the energy was related to the number of molecules, the temperature and a tiny constant factor, *k* – called Boltzmann's constant, after the Austrian Ludwig Boltzmann.

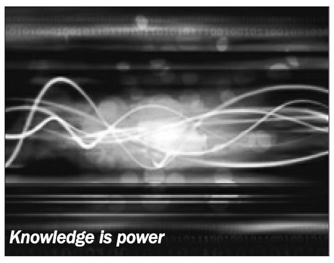
As the energy of the gas was also described in statistical terms, Boltzmann's constant, *k*, got linked with the different ways the speeds of molecules were distributed and the level of "likely" and "unlikely" associated with energy and temperature. The insight developed that what happened when a gas cooled, doing work along the way, was that the gas changed from a comparatively "ordered" to a "less ordered" condition. A bucket of hot and a bucket of cold water represent order, but if we drive a heat engine that takes hot water and cools it to the temperature of the cooler water, we derive energy but we increase "disorder".

Leó Szilárd

Szilárd Leó (the original form of the name) was a Jewish Hungarian physicist who is noted for his work in statistics to develop the theory of the nuclear chain reaction. He also worked with Albert Einstein on information theory and heat engines and wrote a celebrated paper whose title could be described as "on reducing the disorder in a system by the interference of an intelligent being". The paper considered a "thought experiment, first proposed by the scientist Clerk Maxwell, of two containers of gas, at the same temperature, separated by a narrow doorway. Now, if there were an intelligent being, known to physicists as *Maxwell's Demon*, sitting at this door which it opened every time a fast molecule approached from one of the containers, or when a slow one came from the other container, in some time one container would have fast molecules while the other had slow ones. This is the same as saying one container grows hot while the other cools. The two containers could then drive a heat engine and produce work!

The reason why this cannot happen, of course, is that the demon, in its work, must consume energy, and this energy can be shown to be of the same order as the work the heat engine would do. In actual practice, the energy it takes to create such conditions, by charging batteries, for instance, is always much greater than the work we can derive from them, but physicists have been interested to know the theoretical relationship between information processing and energy – how much energy would a real *Maxwell's Demon*, completely energy efficient, consume to produce a given change in temperature?

James Clerk Maxwell.



Knowledge is power

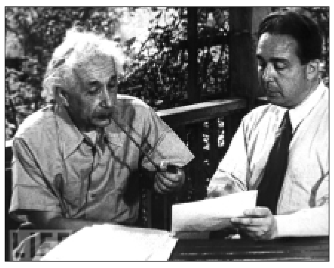
Szilárd Leó's contribution was an elegant theoretical relationship – the work it takes to force a system into one of two possible states is at least about 0.693 times *k* (Boltzmann's constant) the absolute temperature. Now the value of *k*, which has a decimal point followed by 23 zeros, is so small, that the energy content of information is miniscule, indeed. Christian Van den Broeck, writing in *Nature*, has worked out that the energy in a litre of petrol is equal to 10^{18} Gigabits, which is more digital information than humanity has processed so far!

In terms of actual information processing systems, the human brain, says Van den Broeck, consists of some 10^{11} neurons. If the brain is considered to work like a kilohertz binary processor, each neuron does10^{14} bits per second and they consume 100W. The energy consumed per bit comes to about 10^{8} kT per bit, well above Szilárd's estimate of only 0.693 kT. Even a modern gigahertz processor, working at 10W, uses 10^{11} kT per bit. No doubt this is because of all the peripherals that need to be run, but the message is that the Szilárd limit is pure theory of not much practical value.

Practical Value

But physicists are still interested, because, leaving aside macro systems like the human brain or a microprocessor, the unit kT is of the order of ½ kT, which is the energy of a molecule of a gas, for each of the directions it is free to move in (there are three such, left-right, up-down and in-out). This is also the level of energy of processes in individual cells. To know that .693 kT is actually the energy content of a *binary digit* is hence of basic value. It is also important to know if it is actually possible to generate energy, although not very much, from pure information. And it is here that the work of the Japanese scientists becomes important.

Apart from *Maxwell's Devil*, there have been other conceptual "disorder reducing machines". One such would be a lever that works every time



Leo Szilard with Albert Einstein.

a fast molecule strikes it from below. When this happens, the molecule goes back with some loss of energy, the lever uses that energy to turn a spindle and a weight is raised one notch. The spindle has a "ratchet and pawl" arrangement and can turn only one way. Molecules that strike the lever from above hence have no effect. In time, we can see that the gas would cool down and the weight would get raised – a reversal of the way of nature!

The reason this cannot work is that the highly delicate ratchet and pawl required would behave quite randomly in the continuous bombardment by gas molecules and the action of the lever would be quite irrelevant. The collection of such machines all have conceptual flaws and the gallery resembles a museum of perpetual motion machines of the 17^{th} century.

What Tayabe and others at Tokyo have done is create practically a working model of *Maxwell's Demon*. Conceptually, what they did was to create a spiral staircase where each step is separated by energy of the order of kT, with a microscopic particle placed on some steps. Thermal gas molecules tend to knock the particle down or up the staircase, more likely down, when the particle is higher up. But if the experiment could simulate a "block" which prevented the downward step, sooner or later the particle would climb all the way up while the gas cooled.

Along with this set up is the theoretical advance that has been made, of connecting the information content that is going in to permit this kind of gain of energy from the system. In the conceptual "staircase" described here, the input that enables the particle not to tumble down is the information of when it has climbed a step, so that the block could also be moved up. Analysis of the information gathering system could then provide the measure of information employed.

Tayabe and Co created the "staircase" and also the "block" to prevent taking "downward steps" using electric fields. Then they set up the *Demon*, which would say when to switch the "block" field by periodic microscope observation, video capture, image analysis and control of the electric fields. With this system in place, it was possible to rapidly move the particles up the energy staircase at the cost of only the energy within the system, with the help of the information provided.

Analysis of the information input and the resulting energy gain has shown that the system is working at about 28 per cent of Szilárd's efficiency limit! No doubt, the information gathering machinery is elaborate, the microscope, the electronics and also the highly trained operators. But the experiment demonstrates the possibility of direct information to energy conversion – with the prospect of molecular information gathering devices working nanomachines.

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Do we have to die?

It will take time before we can fully comprehend the ageing process, but if and when we do we will be able to improve the end-stage of life and maybe even lengthen it, writes rhishav n choudhury

Thus that which is the most awful of evils, death, is nothing to us, since when we exist there is no death, and when there is death we do not exist.
— Epicurus.

WHY is it that we can wake up and go about our daily routine of work, family and recreation and then suddenly no longer can? Death is the only inevitability in life. Most religions explain death as something that is predetermined, or that He has decided that our time in this world is over; but to find an answer that goes beyond such acceptance of a divine will we need to understand the science behind death. Only when we can understand what death really is can we consider the possibility of delaying or even escaping it.

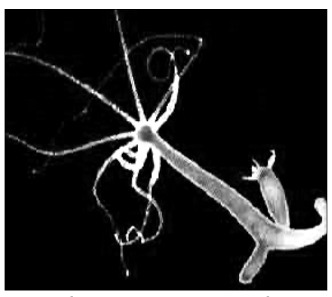
Technically, death is the moment when we take our last breath. Lack of oxygen entering our lungs, to be used by cells to carry out the metabolic functions needed to support life and generate energy, leads to the death of the cells and eventually the entire organism, ie, us. Explaining the causality of death involves an understanding of the challenges cells and complex organisms face as they try to survive.

Life depends on the continual copying and translation of genetic data since, unfortunately, our cells can't continue indefinitely. Cells incessantly get damaged as DNA gets mutated, proteins get damaged, and highly reactive molecules called radicals disrupt membranes, to name a few of the damage-causing agents.

Natural death is usually not a sudden event. The process of ageing is what eventually leads to death and occurs because our body makes a trade-off between using energy for reproduction and to stay in good shape. Reproduction is the basic biological reason for our existence, the need to continue our species. Nearly all of our cells die, the only ones that survive are germ or reproductive cells and that, too, only the ones that fertilise successfully to create offspring.

That sperm or egg that gets fertilised with its opposite number in an amazing process that forms a child which goes on to grow, mature and reproduce to continue human lineage. In a way, it can be said that we never completely die since our genetic material continues. Our remaining body or somatic cells, however, lack this property and due to ageing eventually die. This is because our body receives a limited supply of energy, of which the proportion that goes into making and protecting egg and sperm is far greater than that which is used to maintain somatic cells such as skin, bone and muscle. Due to this lack of maintenance, cells accumulate damage over time, which ultimately causes some organ or the other to become diseased. If body functioning is compromised too much, death takes place.

However, death isn't a certainty for all organisms and in fact certain organisms never die if conditions are suitable. The freshwater hydra is one of the best examples of this form of immortality and has an extraordinary capacity for survival. The hydra does not age — over time it



The freshwater hydra is one of the best examples of a form of immortality and has an extraordinary capacity for survival.

shows no increase in death rate or decline in fertility. On top of that, it is capable of regrowing a whole new body from any fragment of its body if it were cut off. The reason for this extraordinary ability is the fact that every single cell in a hydra is a germ cell with the capability to form a new individual. The immortal germ line is everywhere, enabling the hydra to survive indefinitely as long as it does not succumb to fatal injury or predators.

The factors that control ageing are certain genes that manage an organism's lifespan by organising its metabolism – ie, the way is uses its energy for bodily functions. In most humans, these genes have a generally standard timeline.

Our memory, reaction time and ability to see fine detail generally begin declining after our 70^{th} birthday. Our maximum breathing capacity and heart rate during exercise between 20 and 80 diminishes by 40 per cent and 25 per cent respectively. Our bones tend to get weaker after 35, as bone mineral loss outstrips replacement and after years of pressure our spinal disks and joints tend to slip, bulge and grind against each other. Until the last breath, our body continues to fight for survival but eventually it folds.

Natural selection seems to have placed a higher priority on growth and reproduction in perpetuating the existence of our species than on building a system that could last forever.
So how do we slow ageing? Explorer Ponce de Leon spent a lifetime looking for the Fountain of Youth and Oscar Wilde's Dorian Gray reflects the human obsession with finding any way to delay ageing. The scientific answer may lie in longevity drugs that tinker with cell metabolism or change the way damaged cells behave. Certain therapies might redirect cell metabolism, increasing the amount of energy used for maintenance and repair functions and decreasing the amount used in reproductive functions, allowing organs to remain healthy longer. Calorie restriction may be an answer as well. Several flies, worms and mice increase their longevity by restricting their calorie consumption by 30-50 per cent. This may be due to the fact that a period of famine is a bad time to reproduce, and thus may cause the animal to switch off its fertility and rather divert a large amount of its energy and resources to survival and maintenance. Manipulating damaged cells is a key to slowing the ageing process. Damaged cells tend to commit "suicide" by a process known as apoptosis, or begin to replicate uncontrollably, becoming cancerous, or enter a senescent state in which they function but do not replicate. Rescuing damaged cells from apoptosis, or from uncontrollable replication, or from senescence and inducing their rejuvenation could theoretically protect organs from unwanted effects on injured cells.

Ageing is a complex process and affects the body at all levels, from molecules to cells to organs. It will take time before we can fully comprehend it, but if and when we do, we will be able to improve the end-stage of life and maybe even lengthen it. Life expectancy continues to rise at a rate of five hours a day on average and people live decades longer than what was earlier thought possible. Maybe death isn't as inevitable as we believe.

The writer is a freelance contributor

The rot within

tapan kumar maitra **probes the mechanism of viral infections**

VIRUSES are intracellular obligate parasites. The mechanism of the interaction of a virus with the susceptible cell is a rather complex cycle. It consists of five phases: a) the adsorption of the virus into the surface of sensitive cells; b) penetration into the cell of the virus or its nucleic acid bearing the function of genetic information; c) blocking of cell information; d) synthesis of virus components; and e) release of viruses from the cell.

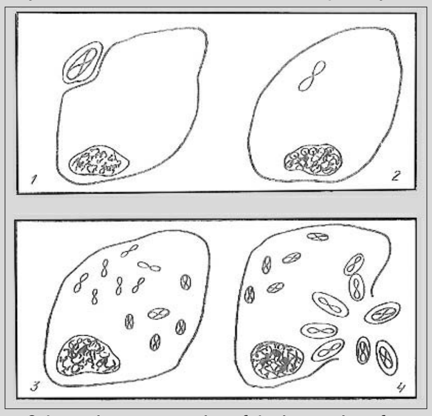
It is assumed that a virus is adsorbed because it becomes attached to the cell receptors composed of mucopolysaccharides or lipoproteins. This process takes several minutes. The virus is held fast by the susceptible cells and loosely by those not sensitive to it. The adsorbed viruses do not necessarily penetrate the cell, but those that do may or may not cause virion reproduction.

Viruses enter the cells of animal and human tissues or organs by pinocytosis with the virion being engulfed by cytoplasmic protrusions of the host cell; protein does not participate in the further development of the infectious process. Before penetrating the cell, the viruses of bacteria, actinomycetes and blue-green algae become free of proteins. It is possible that viropexis and virion disintegration occur in the cytoplasm simultaneously. Some researchers
established that the ribonucleic acid obtained by deproteinisation of virulent and weakly-virulent virus strains possesses an equal scope of genetic information in both cases. For the discovery of the mechanisms of entry of viruses into the cells of organisms M Delbruck, A Haershi and S Luria were awarded the Nobel Prize in 1969.

An important link in the interrelationship of the virus and the cell is deproteinisation — freeing the virus of the protein membranes — the type of which differs with the virus. In poliomyelitis, and other virus infections, the ribonucleic acid free of all membranes of the virion is partly hydrolysed and only about half of it takes part in the synthesis of new virions. Deproteinisation of DNA-containing viruses of the smallpox group occurs in two or three consecutive stages.

The synthesis of virions begins in the fourth phase. The vital proteins form from the amino acids and their arrangement in the polypeptide chain is determined by the information carried by the polysomes — consisting of cell ribosomes — and the viral messenger RNA. The synthesis of virions in the infected cells occurs if there is excess amount of nucleic acids and protein. The ions of metals, calcium and magnesium, carbohydrates and lipids play a definite role in the formation of strong bonds between nucleic acid and protein.

It has been established that the virion components may form in different areas of the cell: the poliomyelitis



Schematic representation of the interaction of a virus and a susceptible cell: 1) the virus is adsorbed; 2) it penetrates the cell and is freed of the protein membrane; 3) virions are reproduced; and 4) mature virions emerge from the cell.

and the variola vaccine viruses, arboviruses, etc are synthesised in the cytoplasm, while adenoviruses and the herpes virus are synthesised in the nucleus.

Synthesis of the protein components of the influenza virus occurs at different sites. The ribonucleotide (S antigen), for example, forms in the nucleus or sometimes in the nucleolus and is then carried to the cytoplasm where it combines with haemagglutinin — a viral protein. On leaving the cell, a mature virus acquires a lipid-polysaccharide membrane. The number of virions formed in a single cell varies from 10-50 in parotitis to 10,000 in poliomyelitis.

A virus is released from the cell in different ways. In some viral diseases its release is attended with destruction of the cells, in others neither the nucleus nor the cytoplasm is disintegrated. Viruses are released as the result of rapid or slow cell destruction.

In infection with large RNA- and DNA-containing viruses new viral antigens appear in the affected cells that make the cell heterologous. As a result, these cells may be destroyed by lymphocytes and macrophages, leading to the development of auto-immune diseases, the underlying factor of which is a chronic virus infection.

Many viruses — the causative agents of measles, chickenpox, epidemic parotitis, viral hepatitis, yellow fever, rubella and the Coxsackie virus — cause damage to the chromosomal apparatus: rupture of the chromosomes, fragmentation, dispersion into the minutest areas and aneuploidy of definite groups of chromosomes.

The extent of the affection and the frequency of occurrence of cells with ruptures and other damages depend on the dose and virulence of a virus. Under the effect of the usual infectious doses, the number of cells — leucocytes of the peripheral blood and bone marrow — increase four to tenfold in persons with viral diseases compared to control experiments.

It is assumed that the changes in the chromosomal apparatus — ruptures, fragmentation and dispersion — may result from the direct penetration of the chromosome by the viral nucleic acid, due to the mutagenic effect of viruses and the products of the general cell metabolism disturbed by a virus.

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