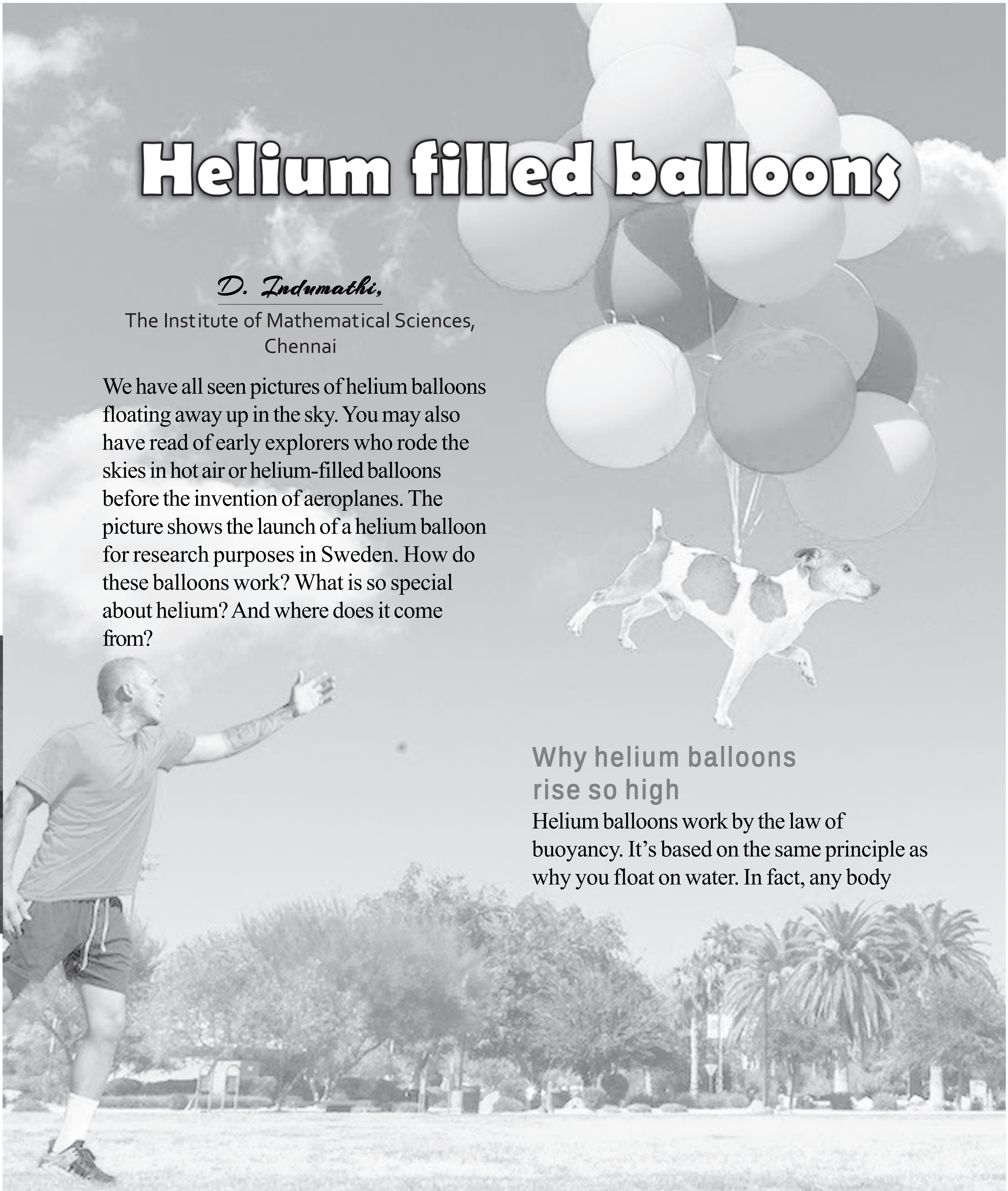
c o n t e n t s

Contents



Helium filled balloons

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Chennai

We have all seen pictures of helium balloons floating away up in the sky. You may also have read of early explorers who rode the skies in hot air or helium-filled balloons before the invention of aeroplanes. The picture shows the launch of a helium balloon for research purposes in Sweden. How do these balloons work? What is so special about helium? And where does it come from?

Why helium balloons rise so high

Helium balloons work by the law of buoyancy. It's based on the same principle as why you float on water. In fact, any body that displaces less weight of water than its own weight, ends up floating on water. While a human body barely floats, a steel plate sinks while an empty steel cup (containing steel and air) floats for the same reason. Helium is lighter than air. Helium weighs 0.1785 grams per litre while Nitrogen (which air is mostly made of) weighs 1.2506 grams per litre. The difference is 1.25-0.18=1.07 grams, that is roughly 1 gram per litre. This means that a 1-litre bottle of air (that is, an "empty" 1-litre bottle!) would weigh just 1 gram more than a similar bottle of helium. This doesn't seem like much but it all adds up.

One way of understanding the law of buoyancy is to look at the effect of gravity. All masses are attracted to the Earth due to gravity, and the force of attraction is proportional to the mass of the body. So the heavier substance is attracted more and the lighter substance is attracted less. So if you have a helium filled balloon, it is attracted less than a similar amount of air to Earth. In effect, it begins to "float" and rises, pushing an equal amount of air downwards. As it rises, it sees a thinner and thinner atmosphere. It keeps rising until the density of air outside equals the density of the helium, at which point it floats in place for ever. Actually, to be more precise, it will rise until the total weight of the helium and the balloon material is less than the weight of the air it displaces. That is why balloons are made of light materials like silk. The picture shows the BLAST research balloon getting ready for launch.

Discovery of helium

Helium is one of the most abundant elements

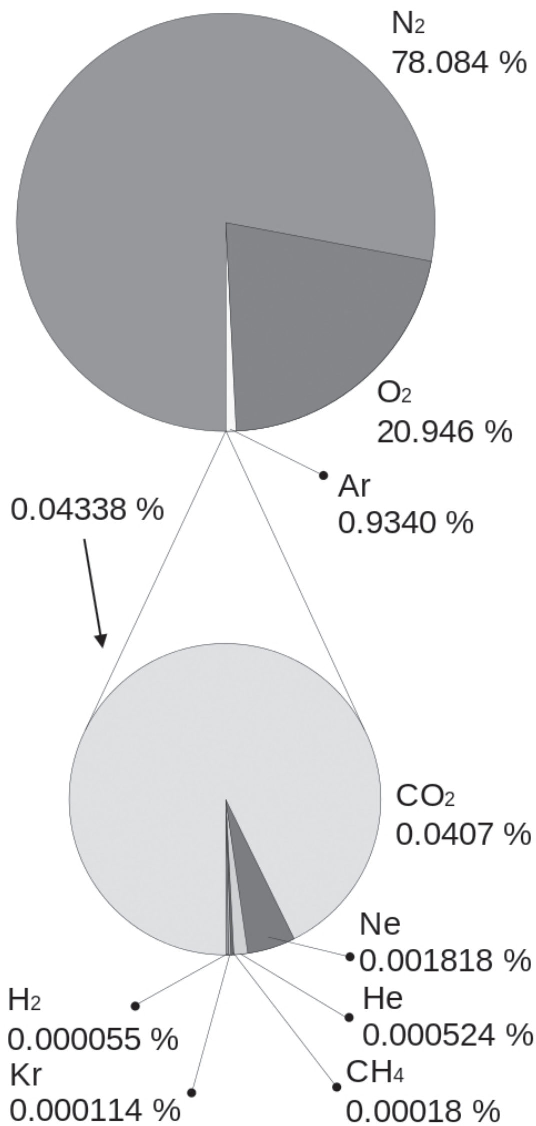
How balloons are used for space flights

Since the difference in weight between helium and air is just one gram per litre, it needs large volumes of helium to lift heavy weights such as men and machines. In order to achieve lift, the total weight of helium as well as the machines must be less than that of the displaced air. Consider the balloon to be spherical. Then we know its volume is (4/3) p r^3 where *r* is the radius of the balloon. For a 10 metre balloon with radius 5 m, the volume is (4/3)x p x (5x5x5) which is about 500 m^3. Since 1 m^3 = 1000 l, this is about 500,000 litres. Since the effective lifting force is 1 gm per litre, such a balloon can lift a cargo of 500,000 gm or 500 kg. NASA and other space and weather organisations send many such balloons into space to understand the composition of the upper atmosphere. Sometimes people such as Jonathan Trappe try and use a bunch of helium balloons to cross the oceans as a fun challenge – see pictures of him and his balloon set up. Hydrogen gas weighs even less than helium, but it is highly flammable.

in the universe, which is made of about 75% hydrogen and 25% helium. Most of it was produced when the Universe began with the Big Bang, but some of it is still being produced in stars. However, most of it exists outside of Earth and its atmosphere. Helium was discovered in 1868, independently by French astronomer **Pierre Janssen** and English astronomer **Sir Joseph Lockyer**. They were studying an eclipse of the Sun using spectrometers.

A spectrometer, as the name suggests, separates light into different bands of colour using a prism. For instance, sunlight is separated into the entire rainbow of VIBGYOR colours by a prism or a spectrometer. However, some light sources contain only certain colours, depending on the atoms or molecules that are present in it. For instance, mercury vapour lamps contain all colours but not a continuous spectrum (the light in a spectrometer from mercury vapour shows bands of colour) while sodium vapour lamps have only yellow light. The colours seen in the spectrum are used to identify the atoms or elements in the gas.

Both scientists observed a band of yellow light from the Sun that could not be identified with any known element. In fact, it was close to the two lines from sodium light, but not



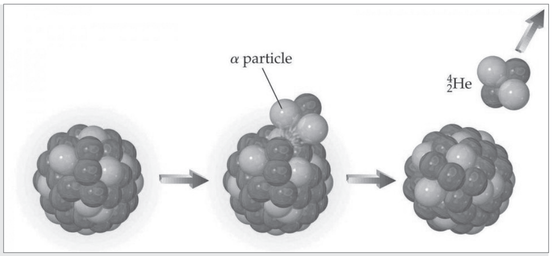
exactly the same. See figure. News of their findings reached the scientific world on the same day, and both men are generally credited with the discovery. Janssen actually travelled to Guntur in India to make his observations.

Lockyer suggested the name helium for the new element, derived from the Greek word *helios* for the Sun. Today we know that

How radioactivity produces helium

Uranium and Thorium are two of the most common radioactive elements on Earth. Radioactive means that, even left to themselves, they decay or transform into other elements. They do this mostly by emitting particles called alpha and beta particles. Alpha particles are helium nuclei, while beta particles are electrons. These exotic names were given when it was not yet known what these emitted particles were. Very often even the “daughter” nuclei, that is, the element into which uranium and thorium decay, are not stable, and they decay as well. This establishes a “decay chain”, with a series of elements being formed, one after another, by emissions of either alpha or beta particles. The chain of decays stops when the final nucleus is stable. This is most often the element lead. There are three series of decay chains where helium is produced in the Earth.

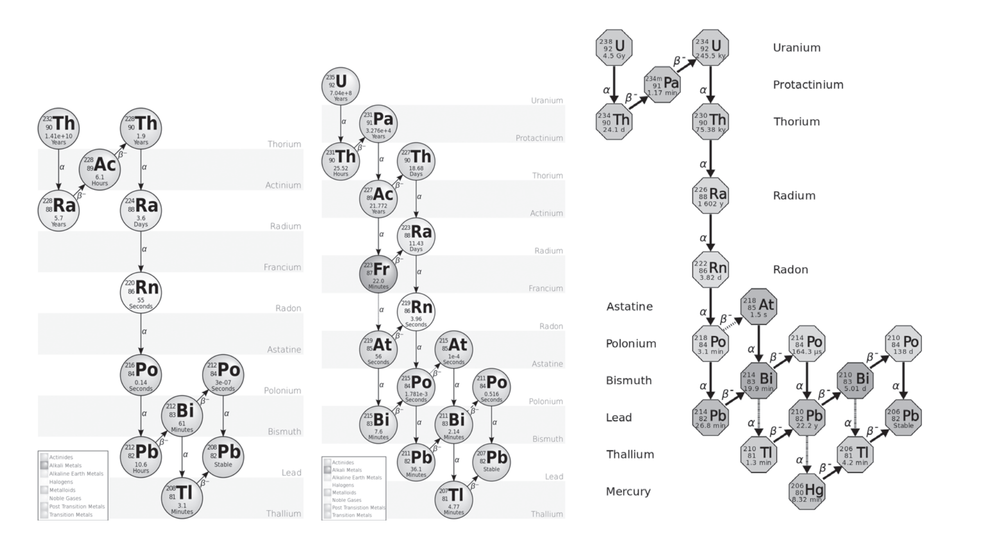
The **thorium series** begins with thorium-232. The number 232 indicates the atomic mass of thorium. Beginning with naturally occurring thorium-232, this series includes the following elements: actinium, bismuth, lead, polonium, radium, radon and thallium. The series terminates with lead-208.

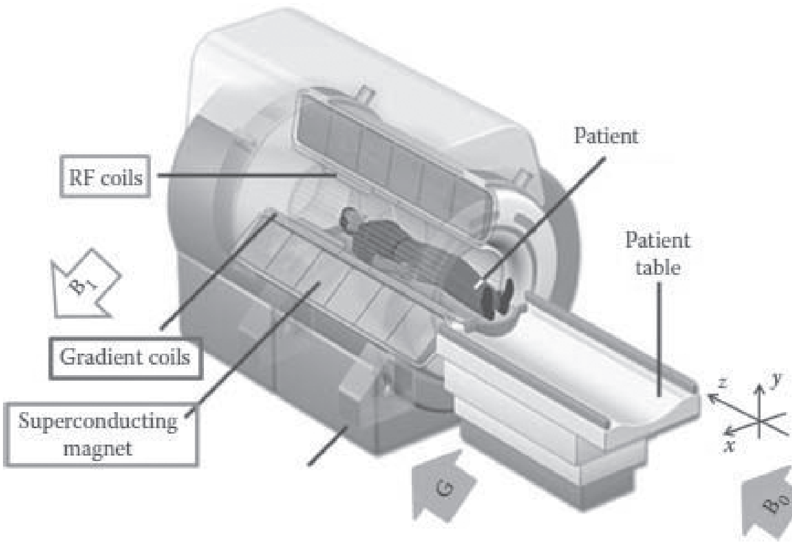


The **actinium series** begins with the naturally-occurring isotope of uranium, U-235. This decay series includes the following elements: actinium, astatine, bismuth, francium, lead, polonium, protactinium, radium, radon, thallium, and thorium. This series terminates with the stable isotope lead-207.

The **uranium series** begins with naturally occurring uranium-238. It includes the following elements: astatine, bismuth, lead, polonium, protactinium, radium, radon, thallium, and thorium. The series terminates with lead-206.

All the decay chains are shown in the figures. The places marked alpha are where helium is produced in the decay.



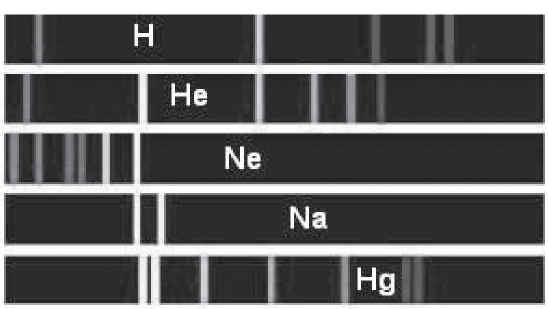


oxygen, and argon (also a rare or noble gas). Gases such as carbon-dioxide, water vapour and some other gases such as methane, nitrous oxide, ozone and other greenhouse gases, are present in small quantities. All these gases are heavier than helium. See figure. Here helium, neon, argon, krypton are rare gases, the lightest of which are present in trace amounts in the upper atmosphere or exosphere.

hydrogen burns to helium in the hot core of the Sun, producing the sunlight that is responsible for all life on Earth.

A Noble gas

Helium has two electrons orbiting around a central nucleus containing two protons and two neutrons. Since only two electrons can fit in the first electronic shell, the shell is complete or "closed" and so helium rarely interacts with any other gas or metal. Hence it is called a rare or Noble gas.
The only gas lighter than helium is hydrogen, which does not occur naturally on Earth. In fact, our atmosphere is made up of nitrogen,



emission line spectra for hydrogen, helium, neon, sodium and mercury

How helium is made in Earth

There is no chemical way of making helium and all the helium that we use has been accumulating in the rocks from decays of radioactive substances such as Thorium and Uranium. See Box. There is hardly any helium in the air. In places that have a lot of uranium ore, natural gas (used for cooking, etc) tends to contain high concentrations of helium (up to 7 percent). The decay of uranium emits lots of alpha particles and alpha particles are just helium nuclei. They can easily acquire two electrons and become helium atoms. The gas (helium and the natural gas) collects in pockets in the underground rock, almost like it is a sealed container. Once the rocks are tapped for their natural gas, the helium gas comes out as well, and will be lost to space if it is not bottled and stored at once. It is separated (cryogenically distilled) out of natural gas to produce the helium we put in balloons.

Other uses of helium

Helium is not just used to fill balloons. It is used in the liquid form in MRIs to cool the magnets because it has a very low boiling point of 4.222 K (“268.928 °C). So it can be used to cool metals down to very low temperatures. This is required for producing superconductivity, which is a state reached by the metal when it has zero electrical resistance (and hence becomes a perfect conductor).

Just think about it: all metals conduct electricity and become hot. You may have noticed this with a light bulb or fan. This means that some of the energy (electricity) you are supplying is being wasted in the form of heat. This is because of the resistance of the metal or wire, which dissipates the energy in the form of heat.

Now, if the metal is cooled below its superconducting transition temperature, no energy is dissipated as heat and the current circulates practically for ever with no loss. Of course, energy is needed to cool the metal below this temperature but after that there are no losses. This is very important in electromagnets where huge currents are required to generate large magnetic fields leading to huge losses due to unwanted heat generation. If the magnets are made out of superconducting material (not all metals are superconductors), they will become cheaper to operate. Hence machines such as MRIs which generate very large magnetic fields (7 T or more) usually use superconducting magnets which are cooled using liquid helium. A large amount of helium is used to cool the superconducting magnets in the Large Hadron Collider (LHC) in Geneva where the Higgs boson particle was discovered in 2012. The LHC uses 96 tons of liquid helium to maintain the temperature at 1.9 K!

Helium is also used in the manufacture of LCDs and fibre optics. It is used in airships, to cool nuclear reactors and infra red detectors, satellite and spacecrafts, and solar telescopes. NASA also uses it to clean fuel from its rockets. The Saturn V rocket used in the Apollo program used about 370 million litres of helium for its launch. While helium is so cheap today that it is commonly used to fill birthday balloons, it is clear that these many uses of helium will soon cause a global shortage. While most of the gas is now found in mines in the United States, Iran and Qatar, other countries such as Tanzania have begun looking for this gas as well.

*Image Credit:
PVerhage - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=3844368; also wikipedia*

Meghnad Saha

(1893-1956)

Indian astrophysicist Meghnad Saha was born in a village near Dhaka, then Dacca in east Bengal, and today the capital of Bangladesh. He came from a humble Dalit background, his father Jagannath was a grocer. Apparently he was named Meghnath, but he renamed himself Meghnad, after Ravana's brother from the *Ramayana*, who was portrayed as a hero in the poem "Meghnad badh" by Bangla poet and dramatist **Michael Madhusudan Dutt**, which impressed him very much.

He had to leave school when caught in the protests of the *swadeshi* movement, which erupted when the province of Bengal was partitioned into two by the British viceroy Lord Curzon in 1905. West Bengal had population with Hindu majority and East Bengal had Muslim majority. Luckily he was a good student, got admission and completed his school exams from Dhaka College. He then studied physics at Presidency College in Calcutta. Most of his work was done while he was at Allahabad University, where he was until 1936. Then he moved to the University of Calcutta.

Saha brought out the journal *Science and Culture* and was its editor until his death. He was concerned about the development of India and discussed such policies in his writings in this journal. In 1951 he won the first election in independent India as an independent and became a Member of Parliament. He did not have money, and his election campaign was funded by sales of his

books and contributions from the public. Till today he remains the only scientist to have been directly elected to the Lok Sabha.

Work as a parliamentarian

In Parliament he was so forthright and clear in his comments that the Congress MPs (that government was under our first prime minister, **Jawaharlal Nehru**) would be terrified that he would point out their mistakes. This is not to say that he was always critical. He helped in the planning of the dams in the Damodar river, which led to irrigation projects, and contributed to the electrification of the states of Jharkhand and

West Bengal. He did not agree with Mahatma Gandhi's ideas of a village-based economy and helped in setting up of the **National Planning Committee** under Netaji Subhash Chandra Bose's Congress in 1938, which after independence became the Planning Commission.

Saha and international recognition

Saha studied with **Satyendranath Bose**, another great Bengali physicist. The works of Bose and Saha and **C V Raman** were considered worthy enough of applying for the Nobel prize. Raman got the Nobel prize in 1930 for his *Raman scattering effect*. Saha was nominated for his *Saha formula*, and Bose for the *Bose statistics*, but they did not win the prize. The picture shows Meghnad Saha with other scientists at Calcutta University (L to R): Meghnad Saha, Jagadish Chandra Bose, Jnan Chandra Ghosh. Standing (L toR): Snehamoy Dutt, Satyendranath Bose, Debendra Mohan Bose, N R Sen, Jnanendra Nath Mukherjee, N C Nag. (Source: Wikipedia).

Saha and his most well-known work on the interior of stars

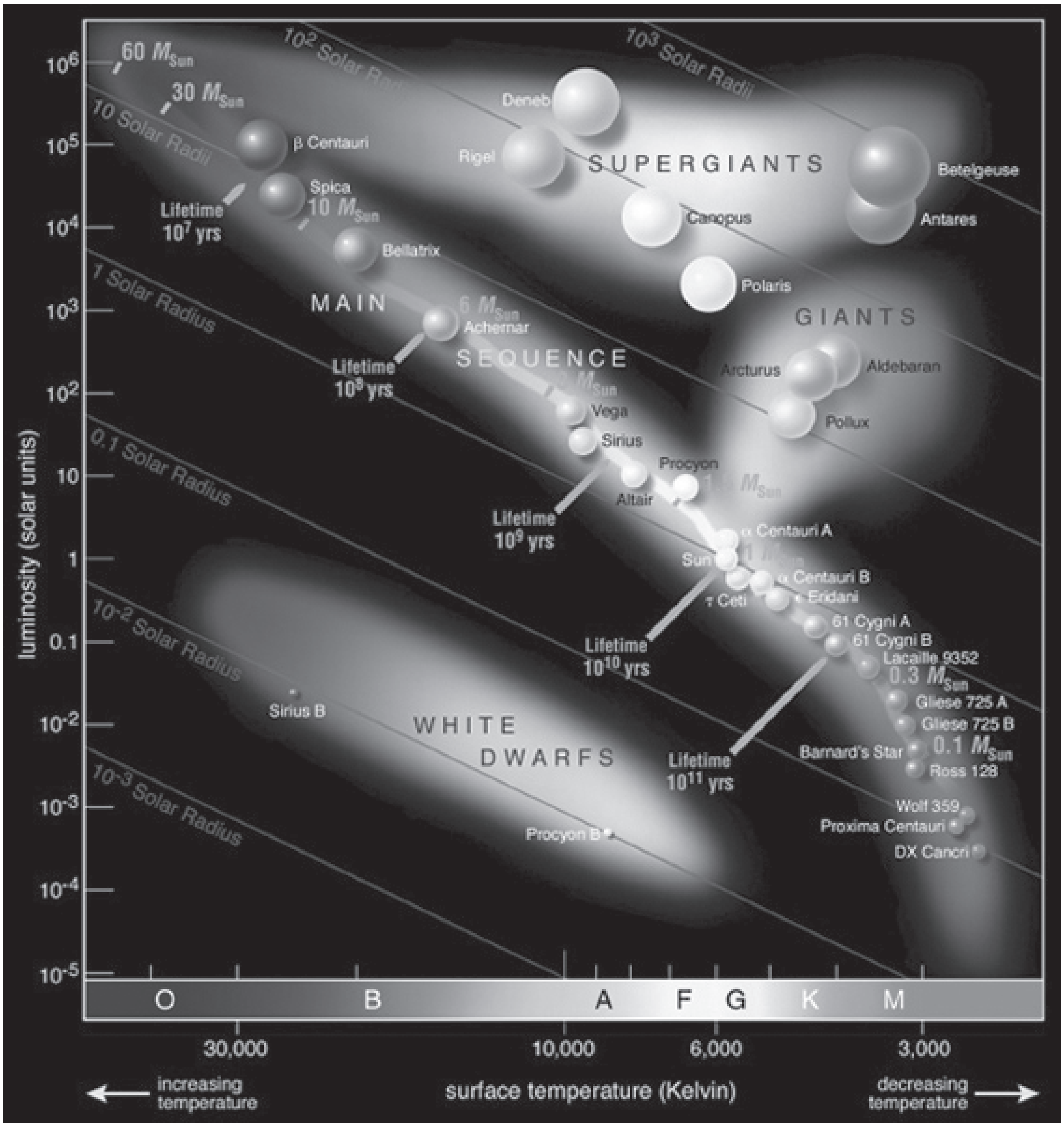
Astronomers such as **Annie Cannon**, **Edward Pickering**, **Ejnar Hertsprung** and **Henry Russell** had realized that the colours of stars were related to their absolute brightness.Most of the time, blue stars are very luminous and red stars much less. (Some exceptional red stars go under the name of "red giants" and some exceptional


Saha with scientists

white stars are called "white dwarfs".) Yellow stars like our Sun are in the middle. This can be seen by plotting a graph that has come to be called the *H-R diagram*, named after Hertzsprung and Russell based on the classification suggested by Cannon and Pickering. The figure shows many well-known stars in our Milky way galaxy, plotted on such a diagram. Look for our Sun with a lifetime of about 10^{10} years and understand why we see Polaris (the pole star) so well.

Stars and ionisation

When observing the spectrum of a star, one can see dark lines in it because elements in



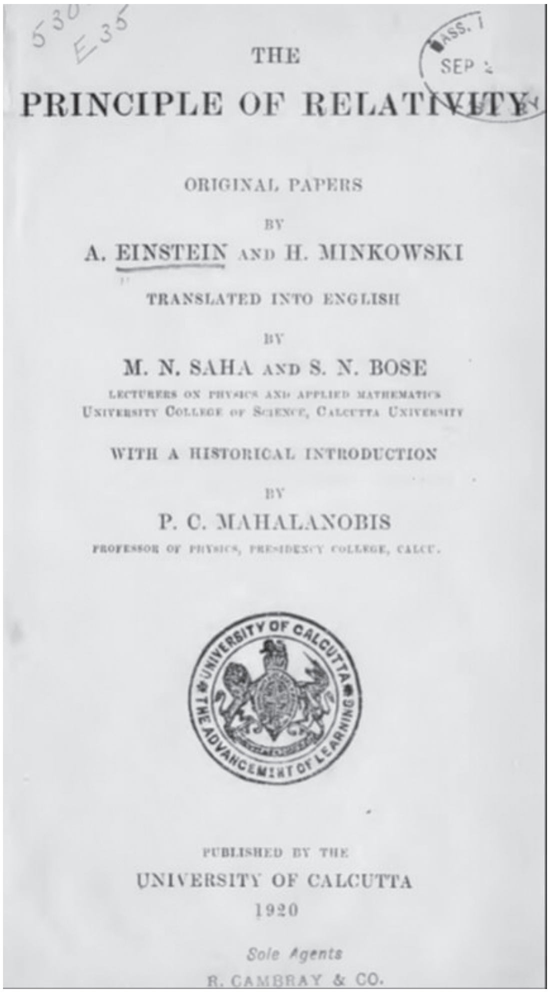
Meghnad Saha
(6 Oct. 1893 – 16 Feb. 1956)
was an Indian astrophysicist best known for his development of the **Saha equation**, used to describe chemical and physical conditions in stars.

$$\frac{n_{i+1}n_e}{n_i} = \frac{2}{\Lambda^3}\frac{g_{i+1}}{g_i}\exp\left[-\frac{(\epsilon_{i+1}-\epsilon_i)}{k_BT}\right]$$

the stellar atmosphere *absorb* the radiation coming from the interior. Some elements are *ionized*, that is, their atoms have lost their electrons. In his 1920 research article, Saha used **quantum mechanics** to find a way of calculating the *temperature of a gas* when the atoms get ionized. He obtained the now-famous *Saha Equation*. Since the spectral line of an ionized atom can be seen with a spectroscope, from its observation we can tell what is the temperature at the star's surface (or maybe even higher up in its atmosphere). Blue stars have very hot surfaces and red stars much less so. Thus the H-R diagram can also be seen as a plot of the stars' **luminosity** (brightness) versus temperature. That is often the meaning given to the H-R diagram today.
Saha requested **George Hale**, director of the *Mount Wilson observatory* which had the largest telescope at that time, to let him study stellar spectra in order to verify his ideas, but he refused. The same calculation

What is the difference between apparent and absolute brightness?

We know that our Sun is just an ordinary star. Many other stars shine much more brightly than our Sun, because they are larger and hence burn more fuel in their interior cores. However, when we look up at the sky, the Sun is the brightest object in it (in the day time, of course), with stars faintly visible only at night. This is because the Sun is very near us. Hence, the Sun has a very large apparent brightness, but in absolute terms, it is not as bright as many stars in our Universe. Astronomers define star brightness in terms of apparent magnitude — that is, how bright the star appears from Earth, and absolute magnitude — that is, how bright the star appears at a standard distance of 32.6 light-years, or 10 parsecs. (A light-year is the distance light travels in one year which is about 10 trillion kilometers.) Astronomers also measure luminosity which is the amount of energy (light) that a star emits from its surface.


THE

PRINCIPLE OF RELATIVITY

ORIGINAL PAPERS

BY

A. EINSTEIN AND H. MINKOWSKI

TRANSLATED INTO ENGLISH

BY

M. N. SAHA AND S. N. BOSE

LECTURERS ON PHYSICS AND APPLIED MATHEMATICS
UNIVERSITY COLLEGE OF SCIENCE, CALCUTTA UNIVERSITY

WITH A HISTORICAL INTRODUCTION

BY

P. C. MAHALANOBIS

PROFESSOR OF PHYSICS, PRESIDENCY COLLEGE, CALCU.

UNIVERSITY OF CALCUTTA
THE ADVANCEMENT OF LEARNING

PUBLISHED BY THE

UNIVERSITY OF CALCUTTA

1920

Sole Agents

R. CAMBRAY & CO.

was later done by American chemist **Irving Langmuir** in 1932. Langmuir won the Nobel prize since he had also done earlier work on gases and atomic structure, which was rated as more of a discovery.

Saha was also deeply inspired by Einstein. He was the first to translate Einstein's works from German to English. The picture shows the cover page of the English translation of Albert Einstein's and Hermann Minkowski's papers on relativity by Meghnad Saha and Satyendra Nath Bose (Source: Soma Banerjee, Physics Today 69, 8, 38 (2016).

Hydrogen and helium in the stars

In her PhD thesis in 1934, the first in astronomy from Radcliffe College in Harvard university, **Cecilia Payne** used Saha's ideas to identify the *quantity or amount of an element in the Sun.* She realized that although there were many lines in its spectrum, they were all due to the usual elements, with different ionizations. She came up with the startling conclusion that most of the Sun (and stars) was made up of just hydrogen and helium. This has been called one of the brilliant PhD theses in astronomy. One of her thesis examiners was **Henry Russell**. He asked her to withdraw that conclusion since it did not match the theories prevalent then (including his own, which said that Earth and Sun had the same composition). Later he realized his mistake when he derived the same result in a different way, and gave credit to Payne.

Saha as a nation builder

Saha published many other papers, co-authored two physics textbooks and wrote many popular articles. He believed in doing science in one's own language. He was the president of the *Indian Science Congress* in 1934. He was involved in the setting up of the *UP* (later *National*) *Academy of Sciences* in Allahabad, the *Indian Academy of Sciences* (which Raman took over) in Bangalore, the *National Institute of Sciences* (now called INSA) in Delhi, and the *Institute of Nuclear Physics* in Calcutta, which is now named after him.

Source:

G. Venkatraman, "Saha and his formula", Vignettes in Physics, Universities Press, 1995.

Do You Know?

1. I know that planets rotate on their own axes. Why does this happen? Are there any special forces that cause this?

2. I heard somewhere: A human can survive 3 minutes without air, 3 days without water, and 3 weeks without food. How long can one really survive without food or water?

3. How does a flame look in zero gravity?

4. Did travellers in the past actually depend on the North Star to guide them? How could they use its position?

Did You Know?

1. Is it really possible to trace a bullet from a crime scene to a specific gun (among all the guns in the world)?

Answer: Yes, almost! There are two processes here. The first is to determine which particular type of gun fired that bullet. Forensic scientists (those who investigate crime using science and technology) can do this very precisely. The second is, given a gun (perhaps found by police in the house of the accused) and a bullet, to find out whether it was that specific gun which fired that bullet.

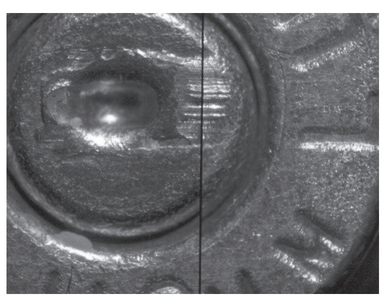
characteristics are imparted to the bullet as it spins down the barrel.

Do you know why bullets are given spin? Hint: What happens to a top when it stops spinning?

The figure shows rifling in a barrel having eight lands and grooves. These are actually titled to the left, as seen from the muzzle-end of a gun. These lands and grooves wll appear as raised and lowered areas, respectively, in the barrel. These leave corresponding impressions on the fired bullet as it zips through the barrel; see figure.

Manufacturers use various cutting and electrolytic processes to introduce rifling into a barrel, and these processes make each barrel unique. A barrel produces individual markings and they can be used by a scientist to determine whether a given bullet was fired from a particular gun.

All this determines the brand and model of gun that could have fired a specific bullet. To check if it originated from a particular gun, forensic examiners use an instrument called a comparison microscope. It comprises two compound microscopes joined by an optical bridge and one set of eyepieces. This lets the



Loop Whorl Arch

examiner evaulate two items on each of the microscope stages at the same time. The examiner fires a test bullet through the given gun, and compares it microscopically with the other crime scene bullet.

At this stage it is not an exact comparison. The examiner just sees how many of the distinctive marks and repetitive marks are present in each. When sufficient correspondence is found, the examiner checks for differences and possible explanations for the differences. If the matches are strong and the existing differences are explained easily, then the examiner concludes, with a high degree of confidence, that the “test bullet” and the “scene bullet” are fired from the same gun.

The figure shows two photos, arranged side-by-side (the black vertical line separates the two). One was taken of a bullet found at a crime scene, and the other of a test bullet fired from a gun which was perhaps used at the crime. It can be seen that special marks and striations/lines on one side smoothly join with those on the other, clearly indicating that both bullets were fired from the same gun.

2. Do we share part of our fingerprints from our parents? How can then one tell

whether some fingerprints found are by a specific person?

Answer: Yes, we do inherit some part of fingerprints from our parents, like we inherit so many other physical characteristics. But then, when we talk of identification of persons using fingerprints, we are talking of specific details that make a fingerprint unique, and these are not inherited.

Humans, as well as apes and monkeys, have so-called friction ridge skin (FRS) covering the surfaces of their hands and feet. FRS comprises a series of ridges and furrows that provide friction to help grasp things and to prevent us slipping — when you climb trees, this is critical! FRS is unique and permanent, unless there is some great damage due to injury causing a scar. Normally, by fingerprints we mean the FRS on the ends of our fingers.

Fingerprints have a general “flow” in ridges that results in three major types: a whorl, loop or arch. It is possible to have just one, two or all three types among your 10 fingerprints. An individual cannot be

identified from fingerprints by pattern type alone. To make an identification, we also need to look at the specific path of ridges and the breaks or forks in the ridges, known as minutiae. There are more identifying features.

Why are patterns inherited, but not the identifying features? This is more complicated. In the womb, as the fetus develops, smooth "volar pads" are formed: these are the raised pads on the fingers, palms and feet. Around week 10, the volar pads stop growing but the hand continues to grow, and the first signs of ridges begin to appear on the pads. The spacing and arrangement of these early ridges (known as primary ridges) is a random process. While the overall geometry of the pad determined the pattern, whorls form if primary ridges appear early, and loops if later, and so on. The pad is eventually absorbed into the hand. Thus pattern type is influenced by genetics, but the exact arrangements of the ridges is random.

How do scientists know all this? Interestingly, the evidence comes from studies of fingerprints from identical twins! Identical twins share the same DNA and, often have very similar size and shape pattern types, but different identifying characteristics. The figure shows the similar but not identical fingerprints of two twins A and B.

So if you compare your fingerprints with your sibling's, you are very likely to see similar patterns, but the FRS would be unique.

3. We know that hot air rises. Then why is it colder at higher elevations?

Answer: It is true that hot air rises. But it also expands, and when you allow air to expand, it cools. This means that if pressure decreases, it is cooler.

In the earth's atmosphere, pressure, which is related to the number of molecules per unit volume, decreases very fast as you go higher in altitude. Thus, if a parcel of air from the earth surface rises (because of wind flowing up the side of a mountain, for example), it expands, from higher to lower pressure. Then it cools.

Thus, as you reach higher altitudes, the atmosphere gets thinner. The total heat content of any system is directly related to the amount of matter present in it. Therefore it is cooler at higher elevation.

The heating of the earth itself also plays a role. The planet is warmed by incoming solar energy. Some of this heat bounces off the outer atmosphere and never reaches the lower atmosphere, and some of it is re-radiated back to space. In addition, the atmosphere acts like a greenhouse to reflect some of the heat back toward the earth's surface. At higher altitudes it is relatively harder to retain this energy as more heat is lost to space.

Scientists can study all these effects and argue not just why it is cooler but also calculate by how much and explain it all quantitatively.

4. Why do I get "goosebumps" at times when I am cold? Then there are other times I get them when it is not cold at all!

Answer: Indeed yes, it is very common for people to feel "goosebumps" when coming out of a cold shower or swim and feeling a wind. There are also other times when you hear a song from a long time ago, the song your grandmother used to sing to you when you were a child, and you feel the same phenomenon. Why do such

seemingly unrelated events elicit the same body reaction? The reason for this is the physiology of emotions.

Physically, what are goosebumps? They are tiny elevations of the skin that resemble the skin of poultry after the feathers have been plucked. We could have equally well called them duckbumps or chickenbumps! They are caused by a contraction of miniature muscles that are attached to each hair. Each contracting muscle creates a shallow depression on the skin surface, which causes the surrounding area to protrude. The contraction also causes the hair to stand up whenever the body feels cold. In fact, the Tamil term for goosebumps means "hair standing up" and not bumps, really.

In animals with a thick hair coat this rising of hair expands the layer of air that serves as insulation. The thicker the hair layer, the more heat is retained. In people this reaction is useless because we do not have a hair coat, but goosebumps persist nevertheless. They are inherited from our animal ancestors.

In addition to cold, the hair also stands up in many animals when they feel threatened. You can see this on a cat being attacked by a dog, for example. The elevated hair, together with the arched back and the sideward position the animal often assumes, makes the cat appear bigger in an attempt to make the dog back off.

People also tend to experience goosebumps during emotional situations. The reason for all these responses is the subconscious release of a stress hormone called adrenaline. In humans adrenaline is produced in two small beanlike glands that sit on top of the kidneys. It not only causes the contraction of skin muscles but also influences many other body reactions. In animals, this hormone is released when the animal is cold or facing a stressful situation, preparing the animal for flight-or-fight reaction. In humans, adrenaline is often released when we feel cold or afraid, but also if we are under stress or feel strong emotions, such as anger or excitement. Other signs of adrenaline release include tears, sweaty palms, trembling hands, and increase in blood pressure, a racing heart or the feeling of 'butterflies' in the stomach.

There is no conscious way to cause goosebumps to occur, as far as we know.

Source:
Archives of Scientific American

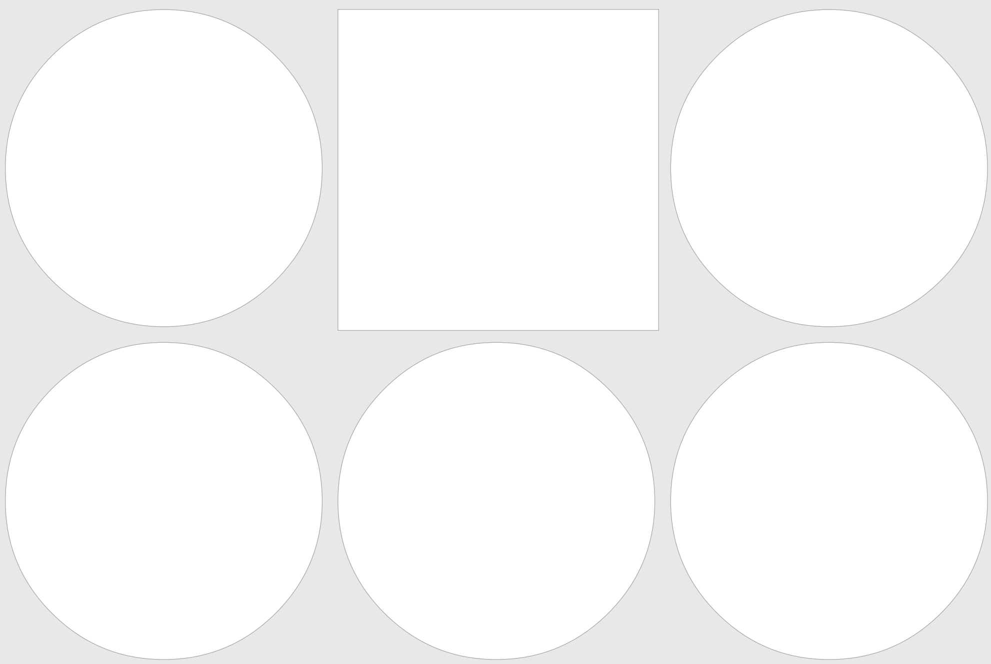
Circling The Square

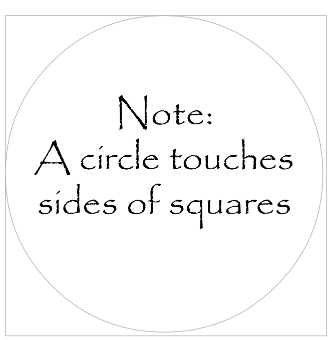
In the diagram below, each circle is just big enough to touch all four sides of the square. The area of the square is therefore just a bit more than the area of one of the circles. I want to know how many of the circles you need to cover the whole square. Is 2 enough? Or do you need 3? Or 4? Or more?

I have put 5 circles for you to play with (print and then cut them out), but what is the least number you need?

Answer on Page 32.

Puzzle Author: Stephen Froggatt, from https://www.mathsisfun.com/





Nobel Prizes

The Chemistry Nobel

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Chemistry 2018 with one half to Frances H. Arnold "for the directed evolution of enzymes" and the other half jointly to George P. Smith and Sir Gregory P. Winter "for the phage display of peptides and antibodies".

The Science

We live on a planet where a powerful force has become established: *evolution*. Since the first seeds of life appeared around 3.7 billion years ago, almost every crevice on Earth has been filled by organisms adapted to their environment: lichens that can live on bare mountainsides, archaea that thrive in hot springs, scaly reptiles equipped for dry deserts and jellyfish that glow in the dark of the deep oceans.

Life on Earth exists because evolution has solved numerous complex chemical problems. All organisms are able to extract materials and energy from their own environmental niche and use them to build the unique chemical creation that they comprise.

Enter **Frances Arnold**. Instead of producing plastics and other chemicals using traditional chemistry, which often requires strong solvents, heavy metals and corrosive acids, her idea was to use the chemical tools of life: *enzymes*. They catalyse the chemical reactions that occur in the Earth's organisms and, if she learned to design new enzymes, she could fundamentally change chemistry.

Arnold starts to play with evolution

For several years, she had tried to change an enzyme called *subtilisin* so that rather than catalysing chemical reactions in a water-based solution, it would work in an organic solvent, called dimethylformamide (DMF). Now she created random changes – mutations – in the enzyme's genetic code and then introduced these mutated genes into bacteria that produced thousands of different variants of subtilisin.

After this, the challenge was to find out which of all these variants worked best in the organic solvent. In evolution, we talk about survival of the fittest; in directed evolution this stage is called **selection**.

In the third generation of subtilisin she found a variant that worked 256 times better in DMF than the original enzyme. This variant of the enzyme had a combination of ten different mutations, the benefits of which no one could have worked out in advance.

With this, Frances Arnold demonstrated the power of allowing chance and directed selection, to govern the development of new enzymes. This was the first and most decisive step towards the revolution we are now witnessing, which is called **directed evolution**.

Today, her research group has developed enzymes that transform simple sugars to isobutanol, an energy-rich substance that can be used for the production of both biofuels and greener plastics. One long-term aim is to produce fuels for a more environmentally friendly transport sector. Alternative fuels – produced by Arnold's proteins – can be used in cars and aeroplanes. In this way, her enzymes are contributing to a greener world.

Smith uses bacteriophages

Bacteriophages are viruses that infect bacteria. Bacteriophages are simple by nature. They consist of a small piece of genetic material that is encapsulated in protective proteins. When they reproduce, they inject their genetic material into bacteria and hijack their metabolism. The bacteria then produce new copies of the phage's genetic material and the proteins that form the capsule, which form new phages.

George Smith's idea was that researchers should be able to use the phages' simple construction to find an *unknown gene* for a *known protein*. When new phages were produced, the proteins from the unknown gene would end up on the surface of the phage as part of the capsule protein. This would result in a mixture of phages that carried multitudes of different proteins on their surface. In the next stage, researchers would be able to use **antibodies** to fish out the phages carrying various known proteins from this soup. Antibodies are proteins that function like targeted missiles; they can identify and bind to a single protein among tens of thousands of others with extreme precision. If researchers caught something in the phage soup using an antibody that they knew attached to a known protein, as a bycatch they would get the thus-far unknown gene for the protein.

Through this experiment, George Smith laid the foundation of what has come to be known as **phage display**. Its strength is that the phage functions as a link between a protein and its gene. Around 1990, several research groups started to use phage display to develop new biomolecules. One of the people who adopted the technique was **Gregory Winter** and it is thanks to his research that phage display is now bringing great benefit to mankind.

The world's first pharmaceutical based on a human antibody

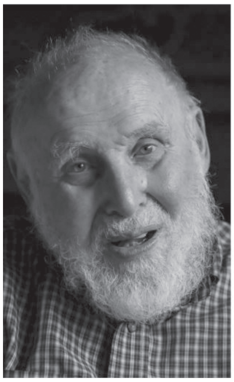
Greg Winter and his colleagues founded a company based on the phage display of antibodies. In the 1990s, it developed a pharmaceutical entirely based on a human antibody: *adalimumab*. The anti-body neutralises a protein, *TNF-alpha*, that drives inflammation in many autoimmune diseases. In 2002, the pharmaceutical was approved for the treatment of **rheumatoid arthritis** and is now also used for treating different types of **psoriasis** and **inflammatory bowel diseases.**

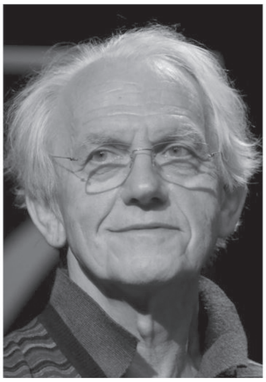
The success of adalimumab has spurred significant development in the pharmaceutical industry and phage display has been used to produce cancer antibodies, amongst others. One of these releases the body's killer cells so they can attack tumour cells. Tumour growth slows down and, in some cases, even patients with metastatic cancer are cured, which is a historic breakthrough in cancer care. Another antibody pharmaceutical that has been approved neutralises the bacterial toxin that causes **anthrax**, while another slows the autoimmune disease known as **lupus**; many more antibodies are currently undergoing clinical trials, for example to combat **Alzheimer's disease**.

The start of a new era in chemistry

The methods that the 2018 Nobel Laureates in Chemistry have developed are now being internationally developed to promote a greener chemicals industry, produce new materials, manufacture sustainable biofuels, mitigate disease and save lives.

Source: The Nobel Prize web-page: https:// www.nobelprize.org



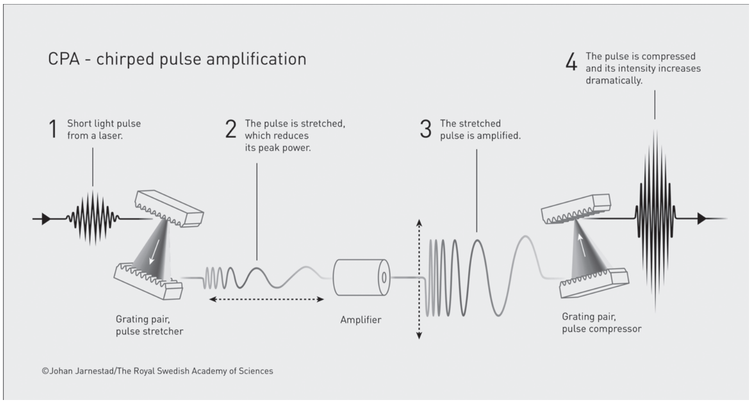


Physics Nobel

The Nobel Prize in Physics 2018 was awarded "for groundbreaking inventions in the field of laser physics" with one half to Arthur Ashkin "for the optical tweezers and their application to biological systems", the other half jointly to Gérard Mourou and Donna Strickland "for their method of generating high-intensity, ultra-short optical pulses."

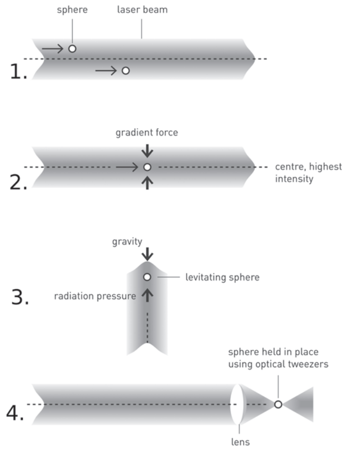
Arthur Ashkin invented *optical tweezers* that grab particles, atoms, viruses and other living cells with their laser beam fingers. This new tool allowed Ashkin to realise an old dream of science fiction – using the radiation pressure of light to move physical objects. He succeeded in getting laser light to push small particles towards the centre of the beam and to hold them there. Optical tweezers had been invented.

A major breakthrough came in 1987, when Ashkin used the tweezers to capture living bacteria without harming them. He immediately began studying biological systems and



optical tweezers are now widely used to investigate the machinery of life.

Gérard Mourou and *Donna Strickland* paved the way towards the shortest and most intense laser pulses ever created by mankind. Their revolutionary article was published in 1985 and was the foundation of Strickland's doctoral thesis. Using an ingenious approach, they succeeded in creating ultrashort high-intensity laser pulses without destroying the amplifying material. First they stretched the laser pulses in time to reduce their peak power, then amplified them, and finally compressed them. If a pulse is compressed in time and becomes shorter, then more light is packed together in the same tiny space – the intensity of the pulse increases dramatically.



Strickland and Mourou's newly invented technique, called **chirped pulse amplification, CPA**, soon became standard for subsequent high-intensity lasers. Its uses include the millions of corrective eye surgeries that are conducted every year using the sharpest of laser beams.

The innumerable areas of application have not yet been completely explored. However, even now these celebrated inventions allow us to rummage around in the microworld in the best spirit of Alfred Nobel – for the greatest benefit to humankind.

How optical tweezers work

1. Small transparent spheres are set in motion when they are illuminated with laser light. See the illustration.

2. The gradient force pushes the spheres towards the centre of the beam, where the light is most intense.

3. Ashkin made the spheres levitate (hover in the air) by pointing the laser beam upwards. The radiation pressure counteracts gravity.

4. The laser beam is focused with a lens. The light captures particles and even live bacteria and cells in these optical tweezers.

Nobel Prize in Physiology or Medicine, 2018

The Nobel Prize in Physiology or Medicine 2018 was awarded jointly to James P. Allison and Tasuku Honjo "for their discovery of cancer therapy by inhibition of negative immune regulation."

About the discovery

Cancer kills millions of people every year and is one of humanity's greatest health challenges. By stimulating the inherent ability of our immune system to attack tumor cells this year's Nobel Laureates have established an entirely new principle for cancer therapy.

James P. Allison studied a known protein that functions as a brake on the immune system. He realized the potential of releasing the brake and thereby unleashing our immune cells to attack tumors. He then developed this concept into a brand new approach for treating patients.

In parallel, **Tasuku Honjo**

discovered a protein on immune cells and, after careful exploration of its function, eventually revealed that it also operates as a brake, but with a different mechanism of action. Therapies based on his discovery proved to be strikingly effective in the fight against cancer.

Allison and Honjo showed how different strategies for inhibiting the brakes on the immune system can be used in the treatment of cancer. The seminal discoveries by the two Laureates constitute a landmark in our fight against cancer.

Can our immune defense be engaged for cancer treatment?

What is cancer? Cancer actually comprises many different diseases. What they all have in common is that the normal cells in some tissues of our body suddenly start to multiply without control. This causes lumps of tissue, called cancer tissue. These cancerous cells also can spread to other healthy organs and tissues nearby.

Accelerators and brakes in our immune system

The fundamental property of our immune system is the ability to discriminate "self" from "non-self" so that invading bacteria, viruses and other dangers can be attacked and eliminated without killing off our own healthy tissues! *T-cells*, a type of white blood cell, are key players in this defence.

T-cells can bind to structures recognized as **non-self** and trigger the immune system to attack it. But it turns out that additional proteins acting as T-cell accelerators are also required to trigger a full-blown immune response. Many scientists contributed to this important basic research and identified other proteins that function as brakes on the T-cells, inhibiting immune activation. This intricate balance between accelerators and brakes is essential for tight control. It ensures that the immune system is correctly positioned to attach against foreign microorganisms. However, if the T-cells then begin to target healthy cells and tissues, the brakes are applied.

What James Allison found

During the 1990s, in his laboratory at the University of California, Berkeley, James P. Allison studied the T-cell protein **CTLA-4**. He was one of several scientists who had made the observation that CTLA-4 functions as a brake on T-cells. He had already developed an antibody that could bind to CTLA-4 and block its function. He now set out to see if the CTLA-4 blockade could remove the T-cell brake. This in turn would activate the immune system which would then attack the cancer cells. Allison and co-workers performed a first experiment at the end of 1994. The results were spectacular. Mice with cancer were cured by treatment with the antibodies that inhibit the brake and unlock antitumour T-cell activity. In their excitement they immediately repeated their experiments over the Christmas break. Yes, it was true. However, there was little interest from the pharmaceutical industry.

Allison continued his intense efforts to develop the strategy into a therapy for humans. Promising results soon emerged from several groups, and in 2010 an important clinical study showed striking effects in patients with advanced melanoma, a type of skin cancer. In several patients signs of remaining cancer disappeared. Such remarkable results had never been seen before in this patient group.

What Tasuku Honjo found

In 1992, a few years before Allison's discovery, Tasuku Honjo discovered **PD-1**, another protein expressed on the surface of T-cells. He meticulously explored its function in a series of elegant experiments performed over many years in his laboratory at Kyoto University. The results showed that PD-1 is similar to CTLA-4. It also functions as a T-cell brake, but operates by a different mechanism. In animal experiments, PD-1 blockade was also shown to be a promising strategy in the fight against cancer, as demonstrated by Honjo and other groups. This paved the way for utilizing PD-1 as a target in the treatment of patients.

Clinical development ensued, and in 2012 a key study demonstrated clear efficacy in the treatment of patients with different types of cancer. Results were dramatic, leading to long-term remission and possible cure in several patients with metastatic cancer, a condition that had previously been considered essentially untreatable.

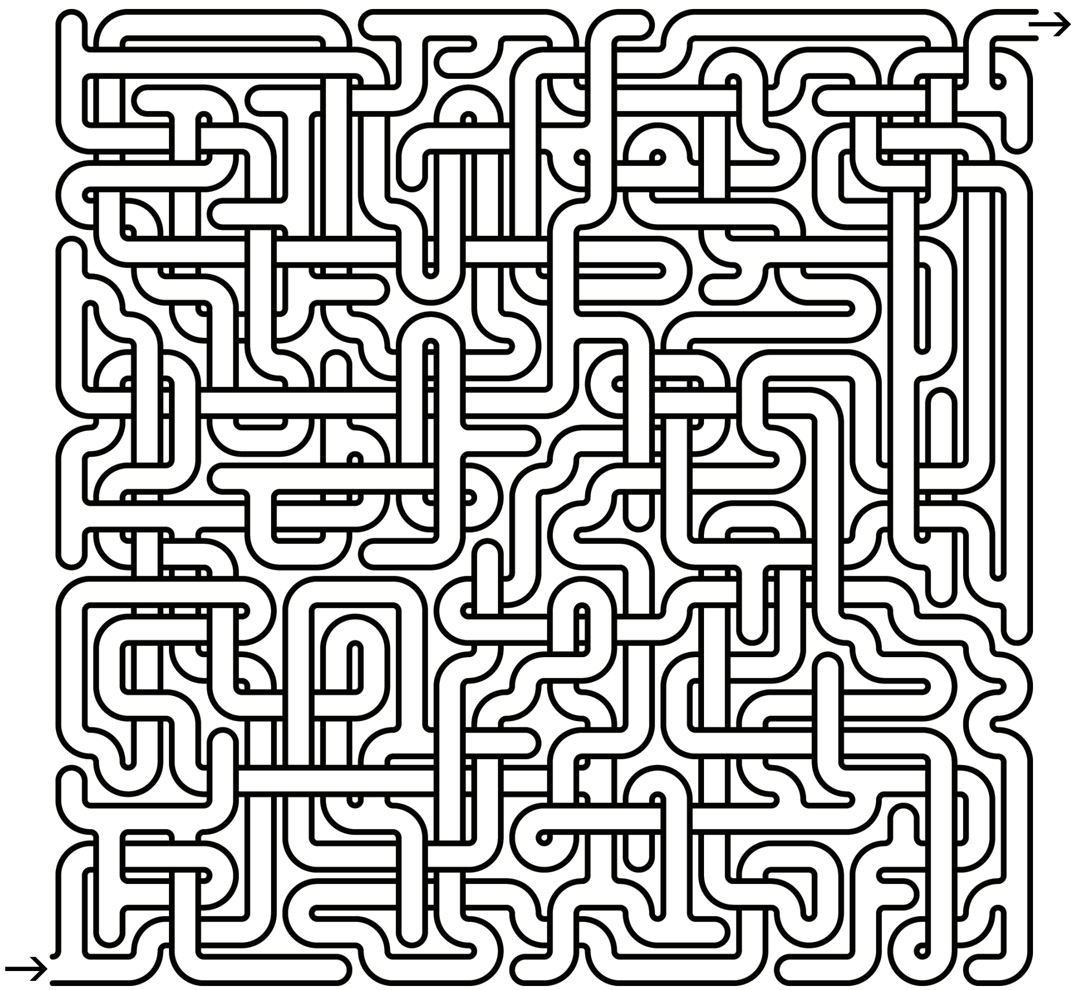
Immune checkpoint therapy for cancer today and in the future

After the initial studies showing the effects of CTLA-4 and PD-1 blockade, the clinical development has been dramatic. We now know that the treatment, often referred to as "**immune checkpoint therapy**", has fundamentally changed the outcome for certain groups of patients with advanced cancer. Similar to other cancer therapies, adverse side effects are seen, which can be serious and even life threatening. They are caused by an overactive immune response leading to autoimmune reactions, but are usually manageable. Intense continuing research is focused on understanding the mechanisms of action, with the aim of improving therapies and reducing side effects.

Of the two treatment strategies, checkpoint therapy against PD-1 has proven more effective and positive results are being observed in several types of cancer, including lung cancer, renal cancer, lymphoma and melanoma. New clinical studies indicate that combination therapy, targeting both CTLA-4 and PD-1, can be even more effective, as demonstrated in patients with melanoma. Thus, Allison and Honjo have inspired efforts to combine different strategies to release the brakes on the immune system with the aim of eliminating tumor cells even more efficiently. A large number of checkpoint therapy trials are currently underway against most types of cancer, and new checkpoint proteins are being tested as targets. For more than 100 years scientists attempted to engage the immune system in the fight against cancer. Until the seminal discoveries by the two laureates, progress into clinical development was modest. Checkpoint therapy has now revolutionized cancer treatment and has fundamentally changed the way we view how cancer can be managed.

Source: Nobel Prize website: https://www.nobelprize.org

Find the way!



Space diary:
Fly and bye

Kamal Lodaya

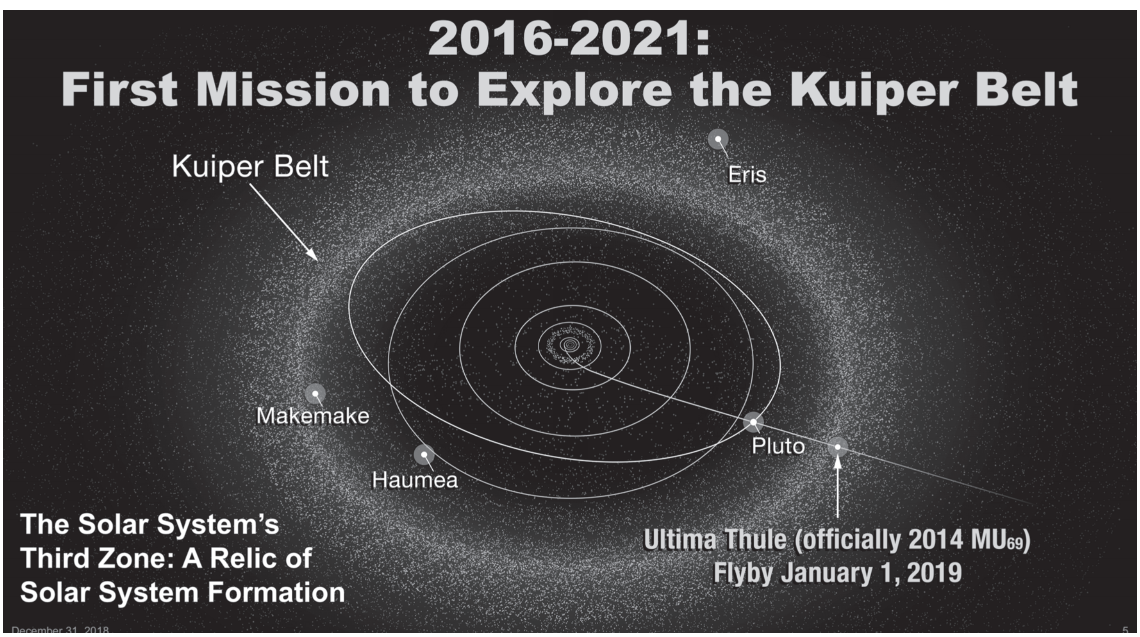
Pluto

Four years ago, the American space agency Nasa's spacecraft *New Horizons* flew by Pluto. As it went by it kept photographing the planet and its five moons. Once it had gone past, it sent the pictures back to Earth. That took a long time, almost a year. So we got pictures of the dwarf planet Pluto. (At one time it was called a planet before astronomers discovered many small bodies of its size.) See the back cover.

Pluto is 5 billion (500 crore) km from Earth. How does one get that far? Launched in January 2006, it took more than a year to cover about 60 crore km to Jupiter. The remaining 450 crore km to Pluto were covered at a faster speed, in a little over 8 years. How come?

The spacecraft took a path which made use of Jupiter's gravity. Roughly speaking, Jupiter picked up the approaching *NH* and flung it out of the solar system. But since all this is the effect of gravity, it can be calculated from the equations set up by British scientist **Isaac Newton** in the 18th century. Nasa's space engineers had pointed the spacecraft in such a way that when Jupiter changed its path, it now was travelling pointed exactly at Pluto! Imagine the accuracy this must have required.

Also, the new path pointed not at Pluto itself, but was such that when the spacecraft would cross Pluto's orbit around the Sun, Pluto itself would arrive as well at that same point its orbit.



New Horizons: The First Mission to the Pluto System and the Kuiper Belt

Mission Overview

Launched: Jan. 19, 2006

Pluto Flyby: July 14, 2015

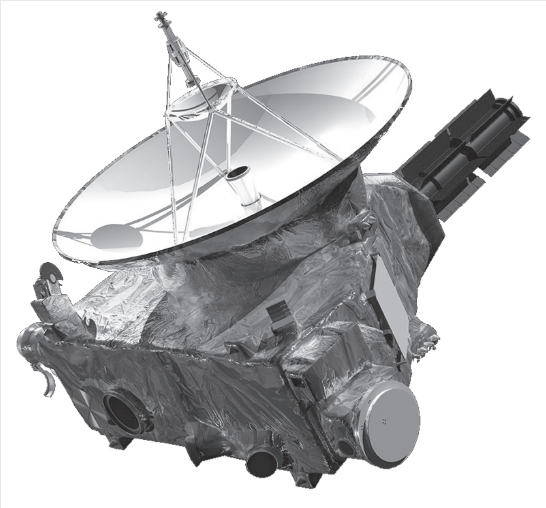
Ultima Thule Flyby: Jan. 1, 2019

Goal: Answer questions about Pluto, its moons, and Kuiper Belt objects.

The New Horizons mission is helping us understand worlds at the edge of our solar system by making the first reconnaissance of the dwarf planet Pluto and by venturing deeper into the distant, mysterious Kuiper Belt – a relic of solar system formation.

The Journey

New Horizons was launched by the Apollo V spacecraft on Jan. 19, 2006. It swung past Jupiter for a gravity boost and scientific studies in February 2007, and conducted a six-month-long reconnaissance flyby study of Pluto and its moons in summer 2015, culminating with Pluto closest approach on July 14, 2015. As part of an extended mission, pending NASA approval, the spacecraft is expected to head farther into the Kuiper Belt to examine another of the ancient, icy mini-worlds in that vast region, at least a billion miles beyond Neptune's orbit.



Farther than Pluto

What happens once the spacecraft goes past Pluto? Well, it just gets thrown out of the solar system. That seems a bit of a waste, with all the money spent on this mission.

Nasa's scientists wanted to make full use of the *NH* spacecraft. Pluto is in the outer reaches of the solar system, a part which is called the **Kuiper belt**, just beyond the orbit of Neptune, where there are many small bodies which go around the Sun. For example, it is from the Kuiper belt that *Halley's comet* comes charging into the inner solar system every 76 years. (It is next

Sending a spacecraft on this long journey is helping us to answer basic questions about the surface properties, geology, interior makeup and atmospheres on these bodies.

New Science

The National Academy of Sciences has ranked the exploration of the Kuiper Belt – including Pluto – of the highest priority for solar system exploration. Generally, New Horizons seeks to understand where Pluto and its moons "fit in" with the other objects in the solar system, such as the inner rocky planets (Earth, Mars, Venus and Mercury) and the outer gas giants (Jupiter, Saturn, Uranus and Neptune).

Pluto and its largest moon, Charon, belong to a third category known as "ice dwarfs". They have solid surfaces but, unlike the terrestrial planets, a significant portion of their mass is icy material.

Using Hubble Space Telescope images, New Horizons team members have discovered four previously unknown moons of Pluto: Nix, Hydra, Styx and Kerberos.

A close-up look at these worlds from a spacecraft promises to tell an incredible story about the origins and outskirts of our solar system. New Horizons is exploring – for the first time – how ice dwarf planets like Pluto and Kuiper Belt bodies have evolved over time.

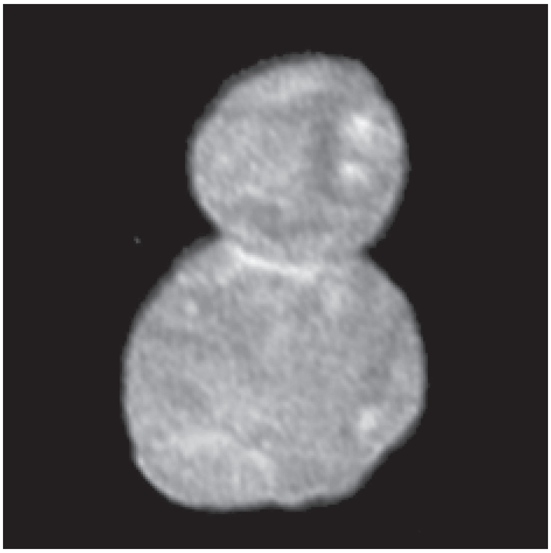
expected in 2061.)

Pluto is about 2400 km in diameter (in comparison, our Moon is 3400 km), a **dwarf planet**. It can be seen from Earth in a large telescope. The other bodies in the Kuiper belt are mostly much smaller, even less than 100 km in diameter. The **Hubble space telescope**, which takes pictures from above Earth's atmosphere, was used in 2014 to search among the hundreds of tiny dots visible in the direction that *NH* was headed for, beyond Pluto, to see if any of them were bodies in the Kuiper belt. (Most of them were stars, so very far outside the solar system.)

Nasa zeroed in on three candidates and then picked one, which is called **2014 MU69**, and decided that *NH's* path could be slightly corrected using its onboard fuel to aim for it. It was given the nickname **Ultima Thule**, which is not an official name. After three and a half more years of travel, *NH* arrived at Ultima on January 1 this year. As it did for Pluto, it took pictures as it passed by and flew on. This one shows Ultima, photographed by *NH* as it was approaching, from more than a lakh km away. Better pictures will arrive from *NH* over the next one and a half years.

Targeting Ultima

This was incredibly more difficult than reaching Pluto. Pluto is tiny compared to Jupiter and one cannot use its gravity to change *NH's* path. Everything has to be



done with the limited fuel available on the spacecraft.

Since Ultima is more than 6 billion km away, it is very hard to see from Earth. But when *NH* was beyond Pluto, Ultima was "only" 2 billion km away! So it was *NH's* camera, called **Lorri**, which took pictures with its zoom lens. Using these pictures, sent back to Earth, the mission engineers did course correction, making sure that the spacecraft would pass less than 2500 km away at its closest. They also verified that Ultima does not have moons, or a dust cloid around it (like a comet might have). At *NH's* speed of 14 km per second, even a dust grain hitting it could severely damage its equipment.

Units of power

As we said above, the signal is sent from *New Horizons* towards Earth using a power of 15 watts. The light bulbs we use at home are around 60 watts. A home tubelight is typically around 40 watts. A cellphone uses around 3 watts. The "beam" which is sent from the spacecraft is very focussed, it only covers an angle of one-third of a degree (as you know, 90 degrees make a right angle). As this beam travels 6.5 billion km, it spreads out farther and farther, so that the amount received, even in the large dish antennas of the **Deep Space Network** of Nasa, is very small. At reception the signal has about a femtowatt of power.

A thousand femtowatts make a picowatt. A picowatt is a very very small unit of power. For example, a single cell in your body uses about one picowatt of power (from chemical energy stored in the cell compounds). You have around 40 trillion cells in your body.

A trillion is a thousand billion, or one lakh crores. A watt is a trillion picowatts, so equals a thousand trillion femtowatts.

Imaging Ultima

Since Ultima is 6.5 billion km from Earth, light, which travels at 3 lakh km per second, takes about 6 hours to reach from there to here. So there was no chance of first seeing Ultima, deciding what to look at, which part of it had interesting features and zoom in on them, and so on. No. The entire sequence of operations, of pointing and photographing, took place in two days and it was pre-programmed and loaded for execution on *NH's* computers in December, a few days before the flyby. After that *NH* would have to do everything on its own.

Imagine, what if you made a mistake? Ultima is so small that mission planners were worried that they might point the camera at the wrong place and get a dark picture showing nothing! What if something which you had not thought about came up? There was a risk that the whole mission could go astray. But space is so empty, that the mission scientists took the chance. They succeeded.

Sending data back from Ultima

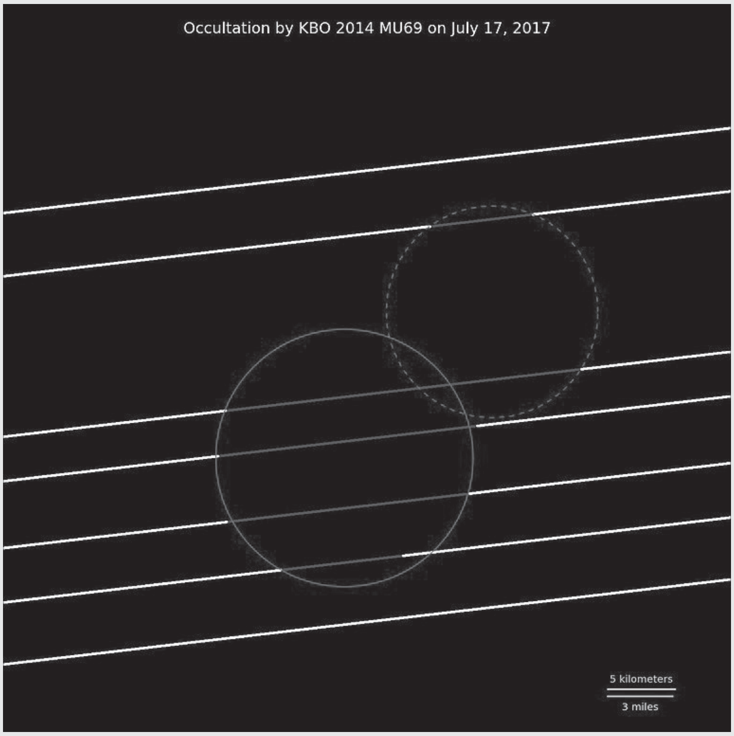
After *NH* had flown by Ultima on January 1, it turned its antenna back towards Earth and started sending the pictures it had taken and the other data that its instruments collected. Remember again that Ultima is very, very far, and the spacecraft has precious little fuel left to power its batteries. Pointing to Earth precisely is very difficult. So getting back all that data will take more than a year, even more than it did for Pluto. But we will get it all. Meanwhile *NH* has first sent some advance images (one of which we saw above) which give us an idea what Ultima looks like.

The signal that Ultima sends uses a power of about 15 watts. As it travels 6 light-hours and 6.5 billion km to Earth, the signal becomes weaker and weaker. By the time it reaches us it is around a femtowatt (see the box for what this is). *New Horizons* uses a very high frequency band which is different from what is used for cellphones, TV and GPS, so all our earthly communication cannot clutter up the space signals. Nasa's **Deep Space Network**, which receives this signal, uses clever techniques to boost this

What can we do from Earth?

Once it was decided that *New Horizons* would visit the Kuiper belt object (KBO) MU69, astronomers came up with ingenious ideas to view it. It turns out that at present the KBO is visible (to huge telescopes like Hubble) in the constellation Sagittarius. Sagittarius is also where the Milky Way is thickest, and there we are looking at the centre of our galaxy, with a huge number of stars. After its orbit was calculated, it was found that MU69 would pass in front of many unnamed Milky Way stars.

Such events are called "occultations". Amateur and professional astronomers fanned out over several places on Earth to photograph and record these observations. The picture shows an occultation on 17 July 2017, captured by telescopes at several locations in Argentina. These telescopes can be of moderate size, but the observer's camera, mounted on the telescope, should be able to record the exact time that the background star "blinked off". Because of the difference in locations, the light from the star went out at very slightly different times, which was measured using very precise clocks. When plotting all the data together, the "snowman" shape of Ultima becomes visible as a hole inside the tracks of light made by the stars! See the picture, that should make the explanation clearer. Astronomers are hopeful that this kind of collaboration between professionals and amateurs can now be used to outline "shapes" for other far-off objects inside the Kuiper belt, which can barely be made out as dots with our biggest telescopes.



signal so that it can be "heard" loud and clear.

It's a snowman!

We saw above the first large-size picture of MU69 (Ultima Thule) sent by *New Horizons*. In our solar system, apart from the nice round planets, we have seen plenty of strange shapes. Saturn's rings were one of the first surprises, discovered in the 17th century. (With his small telescope, the Italian scientist **Galileo** observing it wondered whether the planet had two "handles" on its sides.) The European **Rosetta** spacecraft found the nucleus of comet **Churyumov-Gerasimenko** (CG for short) looks like a duck! Recently the **Hayabusa** spacecraft sent to the asteroid **Ryugu** by the Japanese space agency Jaxa, and the **Osiris-Rex** spacecraft sent to the asteroid **Bennu** by the American Nasa, found that these asteroids are diamond-shaped rather than round.

New Horizons has discovered Ultima to be the first body in our solar system which is a "contact binary". It is two bodies which have collided with each other and stayed that way as they rotate around each other and go around the Sun. It is thought that comets like CG may have formed from contact binaries, but no one knew for sure. Ultima provides the clearest evidence.

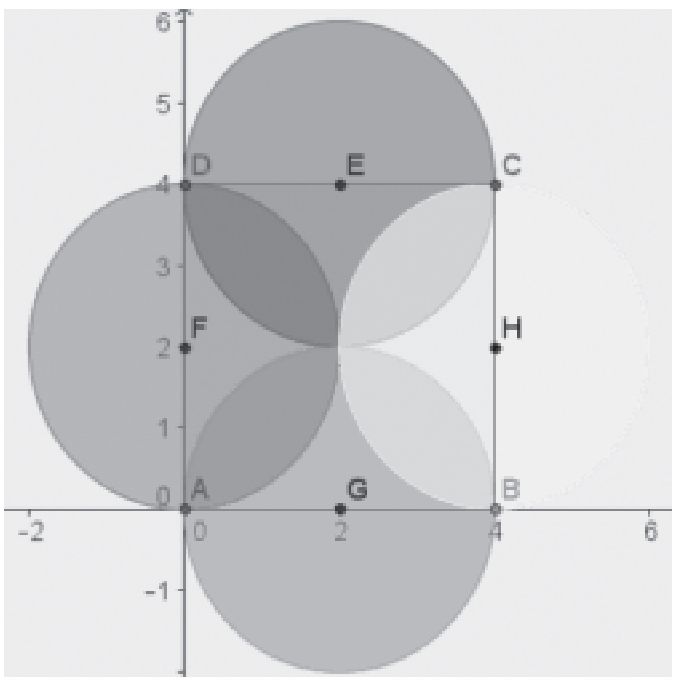
Next season

Now Nasa scientists are thinking, well, now *NH* just goes out of the solar system. That seems a bit silly, with all the money spent on the mission. So can we target something else? The Kuiper belt has many many bodies, and *NH* is only halfway through it so far. Can we find, target *NH* and fly-bye another one over the next 5 years and 3 billion km?

Solution to "Circling the Square"

The actual answer is that you need FOUR circles to cover the square completely. But because it is so difficult to cut out the circles accurately enough to see the tiny gaps that appear, you can be happy if you answered three circles. But four is correct, and you can actually use a program like "GeoGebra" to solve it.

If you have never used Geogebra, go for it, and find that Maths is truly fun!



How it Works

A Differential in a Car

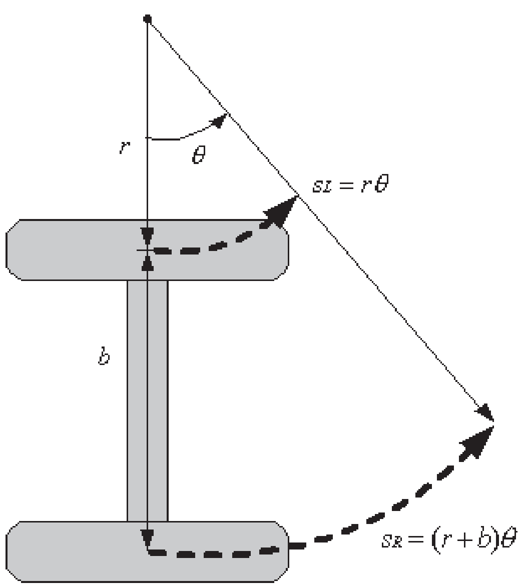
D. Indumathi,
The Institute of Mathematical Sciences, Chennai

A car engine generates power which provides both (rotational) speed and torque. Torque is the turning force that is used to turn the wheels.

When you ride a cycle, you may have noticed that it is difficult to start off, but once you start moving, everything is smooth. The "starting trouble" is due to a large static friction. You need to apply more force to start the cycle moving. Once you are moving, there is only rolling friction to overcome and you do not have to apply so much pressure.

How a car engine works

The same thing happens in a car. A car engine generates power by burning petrol.

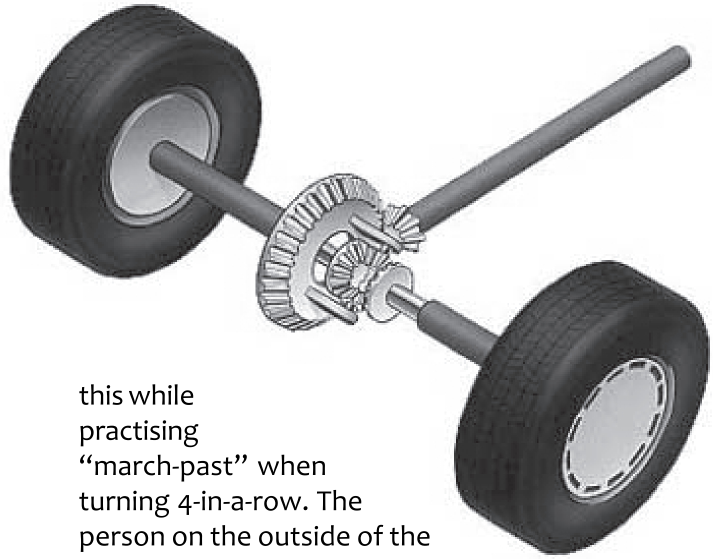


A car engine may have 4 or 6 cylinders. Pistons move up and down the cylinder. When a mixtures of fuel and air burns in the combustion chamber, the resulting hot air expands and pushes the piston down. This in turn moves the crankshaft. The crankshaft converts the up and down motion of the piston into a rotatory movement that allows the wheels to turn so the car moves.

Why gears are needed

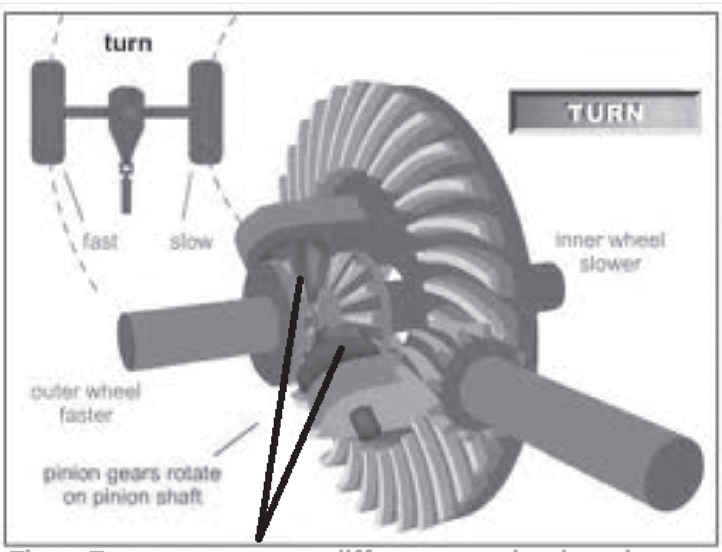
The pistons in the cylinders are pumping up and down at high speeds—about 10-20 times a second. Even when the car is simply idling by the roadside, the pistons still need to push up and down roughly 1000 times a minute or the engine will cut out. In other words, the engine has a minimum speed at which it works best of about 1000 rpm (revolutions per minute). But that creates an immediate problem because if the engine were connected directly to the wheels, they'd have a minimum speed of 1000rpm as well—which corresponds to roughly 120km/h!

Put it another way, if you switched on the ignition in a car like this, your wheels would instantly turn at 120kmph! But there is a problem. It takes a massive amount of force to get a car moving from a standstill and an engine that tries to go at top speed, right from the beginning, won't generate enough torque to do it. To begin with, a car needs a huge amount of torque and very little speed to get it moving, so the driver uses a low gear. In effect, the gearbox is reducing the speed of the engine greatly but increasing its torque in the same proportion to get the car moving. This is because the power generated by the engine equals the product of torque and the angular speed (=2 pi rpm). Once the car starts to move, the driver switches to a higher gear. More of the engine's power converted into speed—and the car goes faster.



So much for gears. What about the differential?

Now you've started the car and it is smoothly moving ahead. You find that you now have to turn left (or right). What happens? When a car turns a corner, one wheel is on the "inside" of a turning arc, and the other wheel is on the "outside." Consequently, the outside wheel has to turn faster than the inside one in order to cover the greater distance in the same amount of time. You may have experienced this while practising "march-past" when turning 4-in-a-row. The person on the outside of the curve has to take really large steps and the person on the inside has to take very small steps in order to keep together. But a car is a rigid object. How to achieve this?



These Two gears move at different speeds when the wheels turn and stay stationary when the car is going straight.

This is exactly where the differential comes into play. A differential is a combination of gears that allows wheels to rotate at different speeds when required, for example, when the car turns. Conversely, the differential must rotate the two wheels at the same speed when the car is moving in a straight line. This prevents the inner wheel from skidding and wearing out, trying to slow down enough to stay with the outer wheel.

For those interested in knowing more, a beautiful 10 minute You-Tube video made in 1937 is available at ***https://www.youtube.com/watch?v=yYAw79386WI***