Did you know that ...

a bacteria is about 10,000 times larger than an atom?

if an object were dropped in a hole dug through the centre of the Earth, it would oscillate like a pendulum?

the famous physicist Richard Feynman was also an accomplished bongo player?

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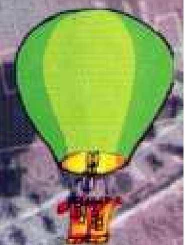

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PHYSICS IN MY POCKET

Shobhit Mahajan teaches physics at the University of Delhi. He has written several books on popular science for children. He also writes regularly for newspapers and magazines.

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For Nitu,
with fond memories of galvanometers!

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Contents

A Peek at History

Why do we feel lighter when we are in water? The answer was first given by the Greek philosopher, Archimedes (287-212 BC), who thought of this when his bath overflowed as he stepped into it. The Archimedes Principle states that, any object immersed in a fluid experiences an upward force, called buoyancy, equal to the weight of the fluid it displaces. It is this buoyancy that makes us feel lighter. This principle also explains why a piece of iron sinks in water while a huge ship floats!

Archimedes was also the first to understand the principle of the lever, though man had used this simple implement for a long time. In fact, he is reported to have said, 'Give me a place to stand and I will move the Earth with a lever.'

Galileo (1564-1642) made many important contributions to physics and astronomy. He discovered the laws of falling bodies and also motion of projectiles. In astronomy, he was the first to use telescopes for observing planets. He discovered

several moons of Jupiter as well as valleys and mountains on the Moon.

Isaac Newton (1642-1727) is considered to be one of the greatest scientists of all times. He formulated the laws of motion and the laws of gravitation that explain the motion of the heavenly bodies. There is a story (probably false!) that he discovered the laws of gravitation when he saw an apple fall! His book *Principia* is thought to be the most significant scientific work of all time.

Newton also established the modern study of light and made the first reflecting telescope. He was the first to show that sunlight is actually made up of seven colours.

Madam Marie Curie was the first person to win two Nobel Prizes in different subjects. Her first Nobel Prize was in physics, in 1903, for research in radioactivity while her second Nobel Prize was in chemistry, in 1911, for discovering radium and polonium. Incidentally, Curie's first prize was shared with

her husband Pierre. Her daughter Irene shared the 1935 Chemistry prize with her husband, Joliot!

Perhaps the most well-known scientist of the 20th century is Albert Einstein. Einstein is well known for his Theory of Special Relativity which explained the true nature of light. He postulated that the speed of light is independent of the speed of the observer and in fact, is the maximum speed by which information can be transferred.

Einstein's Theory of General Relativity explains the nature of space and time and is a more accurate theory of gravitation than Newton's Laws of Gravitation. This theory, which is widely considered the 'most beautiful theory in physics' was verified experimentally during the 1919 total solar eclipse by the astronomer Eddington.

John Bardeen became the first person to win two Nobel Prizes in the same field. In 1956, he got the Nobel Prize in physics for inventing

the transistor, while in 1972, he got the Nobel for developing the Theory of Super-conductivity.

Perhaps the most colourful figure in 20^{th} century physics was Richard Feynman. He formulated the theory of how light interacts with atoms. He was also an accomplished bongo player and picked locks as a hobby! In fact, Feynman got into trouble when he picked the locks in a safe containing the designs of the first atomic bomb during the Second World War!

Some Numbers and Tools

Man has used different units to measure length, mass (weight) and time throughout history. The earlier units were based on standards that could change and were not permanent. For instance, the cubit, an early unit of length was the length from the elbow to the tip of the middle finger!

The metric system of units was introduced in France in the 1790s. The metre has been variously defined as one ten-millionth of the distance between the equator and the North Pole on a line through Paris or in terms of the wavelength of the light emitted by the element Krypton. It is now defined as the distance travelled by light in 1/299,792,458 of a second.

Multiples of the metre are used for measuring different lengths. Thus for instance, one measures small distances in centimetres or millimetres and large distances in kilometres. These units are, however, not suitable when we want to measure distances in the

Universe or even distances in the microscopic world.

The Universe is so large that measuring distances in kilometres makes little sense. Our Sun is 150 million km away while the next nearest star, Proxima Centauri is 40 trillion km away! Measuring these distances in kilometres is like measuring the distance from Delhi to London in micrometres!

Distances in astronomy are measured in light years. Light travels a huge 299,792,458 metres in a second. Light from our Sun takes about 8 minutes to reach us. If we take the distance travelled by light in a year, we get a unit of length called the light year. A light year is roughly 9,461,000,000,000 (9461 billion) km. Thus, the Sun is about 8 light minutes away and Proxima Centauri about 4.2 light years from us. So what we see now of the Proxima Centauri was actually how it looked 4 years ago.

Another convenient measure of distance is the Astronomical Unit (AU) which is defined as the average distance between the Sun and the Earth, about 150 million km.

At one point in history, people thought that the Universe was just a little bigger than the Earth. But now we believe that the Universe is much larger—our visible Universe is thought to be about 10 billion light years across.

Astronomers believe that the Universe that we live in began its life from a Big Bang about 10 billion years ago.

So the age and the size of the Universe are magically the same number. But, there is no magic in it! Since we can only see the Universe to the distance from which light could have reached us since the Universe began, we get a size of 10 billion light years!

In the world of atoms, distances are too small to measure in metres or even millimetres. For instance, the size of an atomic nucleus is one trillionth of a centimetre. That is eleven zeroes after the decimal point and then a one! A more appropriate unit to measure small objects like atoms is an angstrom. One angstrom is 10 billionth of a centimetre. The size of an atomic nucleus is thus about one ten-thousandth of an angstrom.

Another common unit of length that is used frequently nowadays, is a nanometre. A nanometre is a billionth of a metre and scientists are now making devices of this size. This technology is called nanotechnology and holds great promise for the future.

Light waves allow us to see the world around us. However, light is only a small part of a whole electromagnetic spectrum that includes radio waves, microwaves, infrared rays, visible light, x-rays,

ultraviolet and gamma rays. Visible light is the only part of the electromagnetic spectrum that we can perceive.

All forms of electromagnetic radiation travel at exactly the speed of light. The only difference between them is their wavelength, or the distance between successive crests or troughs, of the wave. Radio waves have wavelengths from 1 cm to about 1,000 m while X-rays are a billionth of a metre.

Visible light rays have wavelengths of around 5,000 angstroms.

Different electromagnetic radiations have different properties that make them useful or harmful for us. For instance, we can use microwaves to cook food and X-rays to get images of our bones. Some forms of electromagnetic radiation like gamma rays or ultraviolet rays can be harmful to living things. The ozone hole in the atmosphere is dangerous because it lets in ultraviolet radiation from the Sun.

The force of gravity is responsible for not only the path of a cricket ball but also for the motion of planets. Gravity is only one of the four fundamental forces known to us. It is the weakest of the four forces. All objects that have a mass, experience this force.

Another everyday force is the electromagnetic force. Electrical and magnetic forces, though seemingly different, are manifestations of this force. The electromagnetic force acts on bodies that have a property called the electrical charge and this force is significantly stronger than the gravitational force.

Electric force is at work in a streak of lightning while magnetic forces cause iron to be attracted towards a magnet. Earth also has a very weak magnetic field that allows us to use a magnetic compass in case we get lost in a forest!

Like charges repel each other and unlike charges attract each other. This force between charges is what is responsible for most chemical reactions and hence most of our everyday phenomena.

The other two fundamental forces are the strong nuclear and the weak nuclear force. These forces only act in the domain of subatomic particles. These are responsible for the stability of atomic nuclei as also the decay of nuclei by radioactivity. Radioactive rays and particles are what nuclear bombs as well as nuclear reactors emit.

Radioactivity is useful for dating archaeological and geological material. While radiocarbon dating is used to find out the age of objects that were once living (like pieces of wood, bone etc), potassium-argon dating is used to determine the ages of rocks.

The Very Big

The night sky is full of thousands of 'stars'. Though for us all these are stars, astronomers place them in different groups depending on their properties. In fact, most of these glowing objects are not stars at all but are collections of stars called galaxies.

Our own galaxy, the Milky Way, has about a trillion stars. It is a spiral galaxy with several arms coiling around a central bulge that is about 10,000 light years thick. The diameter of the disc is about 100,000 light years.

Like the Earth, the Milky Way rotates about an axis passing through its poles. The period of rotation of our Solar System is about 200 million years. Due to this rotation, the Solar System is moving at a speed of about 220 km/sec!

The most well-known star is our Sun. It is called a main sequence star. The Sun and other stars like it, give off huge amounts of energy. The source of this energy is nuclear reactions using hydrogen as fuel—

similar to what happens in thermonuclear (hydrogen) bombs. The Sun is about 5 billion years old.

As the Sun grows older, it becomes hotter and brighter. In about 3 billion years, it will be hot enough to boil our oceans!

After the Sun finishes all its hydrogen, it will start expanding. It will engulf the planet Mercury and become a Red Giant. In about 5 billion years, the Sun would have swallowed our Earth too!

A Red Giant, as the name suggests, is a gigantic star—typically 10 to 1,000 times the size of our Sun. A Red Giant gives off much more energy than stars like the Sun. In fact, most of the stars that you see at night are Red Giants because they glow very brightly and can be easily spotted.

When a star like the Sun has exhausted all the nuclear fuel in its core, it contracts due to its own gravity to become a very small and heavy object called a White Dwarf.

A White Dwarf typically is the size of our own Earth but has almost 70% of the mass of the Sun! Which in effect gives these objects a density of 600 million kg per cubic m! That is, a teaspoonful of this star weighs about 3,000 kg!

Because these stars are so small, they are difficult to see with the naked eye. But astronomers can see them using their telescopes. In fact, the brightest star in the sky, Sirius A or Dog Star has a companion star which is a White Dwarf.

In 1844, the German astronomer F Bessel detected that the motion of Sirius A was irregular. Since there was nothing to cause the irregularity, he proposed that there is an invisible companion star that

exerts a gravitational pull on Sirius. This was indeed, discovered to be true, in 1862. Such stars that orbit each other are called Binary Stars.

Not all Red Giants end up as White Dwarfs—some massive Giants become neutron stars after their nuclear fuel has been exhausted. These stars are composed of neutrons that have fused together from atomic nuclei. Neutron stars are very dense. A typical one will have about 2-3 times the mass of our

Sun packed into a region about 20 km in diameter—the size of a small town! One teaspoonful of a neutron star would weigh an enormous billion tons!

Some neutron stars give out their energy in pulses. These are called pulsars and were first discovered in 1967. The pulses of radio waves are so regular that initially it was thought that they might be from some extraterrestrial civilisation trying to communicate with us. Now we know that they are from neutron

stars which are spinning very rapidly, sometimes even several hundred times a second.

Some of the most enigmatic objects in the Universe are Black Holes. These are extremely dense invisible objects that have so much gravitational force that not even light can escape from them! A Black Hole with the mass of our Sun would only be 3 km across!

If you throw a ball upwards, it returns to the ground. If you throw the ball with greater speed it will reach a higher point. As the ball is thrown at greater and greater speeds, it will finally escape the gravitational pull of the Earth. This speed is called the escape velocity and for our Earth it is 11.2 km/second while for the Moon, which is much lighter than the Earth, it is only about 2.4 km/second.

The escape velocity of a body depends on the gravitational pull of

the body. Imagine a body that is so heavy that the escape velocity is the speed of light! Einstein proved that nothing can move faster than light, so it is clear that nothing—you, a spaceship or even light—can escape from this monstrous celestial object. Such an object is called a Black Hole.

Since light and other forms of electromagnetic radiation cannot escape from a Black Hole, astronomers use indirect methods to study them. The Black Hole, because of its immense gravity, sucks in matter from nearby objects. This matter, while falling towards the Black Hole, gives out radiation that can be observed.

Another indication of the presence of a Black Hole is when stars move at enormous speeds around an invisible object. For instance, astronomers have observed about 20 stars orbiting the centre of our galaxy at a speed of about 5 million km/hr! They therefore surmise that the centre of our galaxy has a heavy

Black Hole whose gravity is causing the stars to move at such speeds.

Quasars are relatively small objects that are usually found at the centre of galaxies. Quasars give out a lot of energy and are believed to be associated with Black Holes. In 1998, a quasar was detected which gives out more than 30,000 times the energy emitted by the Milky Way! And remember, the Milky Way has billions of stars.

The Solar System consists of the Sun, nine planets, comets, asteroids, meteors, interplanetary dust and gas. The most distant planet, Pluto is about 40 times as far from the Sun as Earth is, or at 40 AU (astronomical units). The boundary of the Solar System, called the heliopause is said to be about 100 AU.

Comets, considered by some as 'heavenly messengers' are also part of our Solar System. They are small objects made up of rock and ice that revolve around the Sun. As the

comet approaches the Sun, some of the ice turns into gas and together with the dust forms a huge tail. The most famous comet, Halley's comet, is seen every 76 years. In 1994, comet Shoemaker-Levy crashed into Jupiter, creating fireballs the size of the Earth.

Asteroids are small planets in our Solar System that are found primarily in a belt between Mars and Jupiter. They vary in size—the largest, Ceres, has a radius of about 500 km while most are no bigger than a grain of dust. They are believed to be remnants of a planet that could not be formed because of the gravitational pull of Jupiter.

The Sun, as we have seen, uses nuclear reactions to provide energy. Every second, it destroys 600 million tons of hydrogen! However, with a mass of about 2 thousand trillion trillion (2 x 1027) tons, it can glow for about 6 billion years!

The Moon is responsible for one of the most spectacular celestial events —the total solar eclipse. By a curious coincidence of nature, the Moon is 400 times smaller than the Sun as also 400 times closer to us than the Sun. Thus, at new Moon, it is exactly between the Earth and the Sun, and can cover the entire face of the Sun, causing a total solar eclipse. But this does not happen on every new Moon because the orbit of the Moon is slightly tilted.

Though countless stars in the Universe are believed to have planets orbiting them just like our Solar System, these planets are too small to be seen by the naked eye. Scientists have identified over 100 such extra solar planets.

The Universe can be observed through telescopes either based on Earth or in space. The biggest ground-based optical telescopes are on the top of Mauna Kea, a dormant volcano in Hawaii. The Hubble Space Telescope was launched in

1990 and orbits the Earth, transmitting images of the Universe that are several times sharper than those seen from telescopes on Earth.

Apart from the well-known optical telescopes that collect visible light, there are now telescopes that cover almost the whole range of the electromagnetic spectrum—from radio waves to gamma rays. These have proved to be immensely useful in increasing our understanding of the Universe.

The whole Universe is filled with microwave radiation that is a remnant of the Big Bang, the event that is believed to have given birth to the Universe. The radiation has been studied by satellites and is an invaluable tool for understanding the early Universe.

The Universe we live in is expanding, a fact first studied by Edwin Hubble in the 1920s. The galaxies and everything else in the Universe is moving away from us at a speed that depends on how far

they are from us.

Light takes time to travel from the stars to us, the light from the farthest stars started its journey a long time ago. For instance, light from a galaxy 1,000 million light years away started 1,000 million years ago and thus allows us to see how the galaxy was then. In our Universe, looking into the distance is like looking into the past! This allows us to study the early Universe.

The Very Small

Nature is composed of about 100 naturally occurring elements. Besides these, scientists have made about 20 elements in their laboratories. Most of these man-made elements are very short-lived.

The basic building blocks of matter are atoms. An atom is the smallest particle of an element that exhibits its chemical properties. Atoms are tiny—10 million of them in a row would only measure 1 millimetre! Each element has a different atom that gives it its unique properties.

Atoms of an element or of different elements can interact with each other to form all the substances that we see in nature around us—from water to complicated proteins in our cells.

When two or more atoms combine they form a molecule. Chemical substances cannot be infinitely divided into smaller fractions of the same substance. A molecule is the smallest part of a substance that has all the chemical properties of that substance. Each substance in nature has a different kind of molecule.

Molecules are held together by intermolecular forces. Strong forces between molecules of a substance lead to the formation of a solid while weak forces lead to the formation of liquids and gases.

An atom can be thought of as a cloud of negative particles called electrons surrounding a very small nucleus. The nucleus is made up of positive particles called protons and neutral neutrons. The number of electrons and protons are equal, making the atom electrically neutral as a whole.

The nucleus is much smaller than the atom. If the atom was the size of a cricket field, then the nucleus would be the size of a pea!

Electrons are believed to be points in space with no structure. They are among the lightest particles known to us. An electron weighs about a billionth, billionth, billionth of a gram or 10^{-27} grams! The electric charge of the electron is taken as one negative unit and all other charges in the atomic world are measured in terms of this.

Protons are about 1,840 times heavier than electrons and carry one unit of positive charge. Protons are made up of even more fundamental particles called quarks.

A neutron is slightly heavier than a proton but carries no charge. It, too, is made up of quarks. Without the neutrons, the atomic nucleus would blow apart because of the electrical repulsion between the protons.

Scientists now believe that protons and neutrons are made up of particles called quarks. There are six different kinds of quarks that have been given fancy names by scientists to distinguish them. These are up, down, strange, charm, top and bottom! These names have nothing to do with their properties and are used only as labels.

Quarks have strange properties. Unlike all other subatomic particles which carry an integral charge, quarks carry fractional charges (in

units of the electron charge). For instance, the up quark carries a charge of +2/3 while the down quark has a charge -1/3. However, a proton is made up of 2 up quarks and a down quark, giving a net charge of +1. Quarks are very tiny compared to protons. If a proton is drawn as a ball of 1 cm size, the quarks will be thinner than the diameter of a human hair!

Apart from the electrons and quarks, there are other fundamental particles like the neutrino. A neutrino is a particle that is neutral and is believed to have no mass. It feels no electromagnetic forces and is so small that it is hard to detect. In fact, a neutrino can pass right through Earth without any interaction with any other particle! Neutrinos are produced in nuclear reactions like those happening in our Sun. Electrons and neutrinos belong to a type of fundamental particle called the lepton.

Just like we have different kinds of quarks, there are different kinds of

leptons. Apart from the electron, we have the muon and the tau particle, each carrying a unit negative charge like the electron and each with a neutrino associated with it. Thus, there is an electron neutrino, a muon neutrino and a tau neutrino.

These particles also have another strange property—all of them come with their twins called antiparticles! An antiparticle has the same mass as the particle but has the opposite charge. For instance, a positively charged positron is the antiparticle of the electron and weighs exactly the same as the electron.

Other inhabitants of the particle zoo are fundamental particles called gauge particles. These are particles that carry the fundamental forces mentioned earlier.

Scientists believe that light or electromagnetic radiation is made up of small particles (or quanta) called photons. A photon is an

example of a gauge particle. It has no mass or charge and always travels at the speed of light! Photons of different forms of electromagnetic radiation have different energies. Thus, a radio wave photon is much less energetic than a gamma ray photon.

A microscope allows one to see very small objects like blood cells and bacteria. But since atoms are much smaller (a bacteria is about 10,000 times larger than an atom!), scientists have developed special instruments to 'see' atoms and subatomic particles like electrons and protons.

The Electron Microscope is an instrument that uses a beam of electrons instead of light, to form an image. Electron microscopes have been used to make images of a collection of atoms, though not yet of an individual atom.

Particles accelerators are machines used to study subatomic particles. The particles are generated in a beam and then accelerated. Once they achieve a high speed, they collide with each other or with other particles. The resultant collisions give us information about the nature of these particles. Electrical fields are used to speed up the particles while magnetic fields are used to bend the beam of particles.

The largest particle accelerator in the world is the Large Hadron Collider

(LHC) near Geneva in Switzerland. It has an underground tunnel 100 m deep with a circumference of 27 km. Protons are accelerated to almost the speed of light in this tunnel. The magnets in the accelerator are superconducting and produce a magnetic field which is 1,00,000 times that of the Earth.

Our Everyday World

The motion of everything, from cars to planets is described by Newton's three Laws of Motion. The First Law says that 'an object will continue to move at a steady rate or be at rest unless an external force acts on it'. This is what makes us move forward when a car brakes suddenly. This is also the law that allows a spacecraft to keep moving in a straight line without firing its rockets when it is far from the Earth or any other object in space.

Newton's Second Law of motion

relates the acceleration of a body to its mass and the external force acting upon it. It states that 'for the same force, a heavier object moves more slowly than a light one'.

Newton's Third Law simply states that 'for every action there is an equal and opposite reaction'. The action and reaction act on different bodies. When a rocket fires and throws out gases backwards at a great speed (action), the rocket itself experiences a force in the forward direction (reaction).

A simple machine is a device that reduces the effort needed to do some work. Man has used simple machines since antiquity. Examples of simple machines include lever, pulley, inclined plane and wheel and axle. Perhaps one of the first machines used by man was a lever to move heavy objects with the help of sticks of wood and a rock. All our complicated machines, from cars to huge bulldozers are made up of parts that work on the principles of these simple machines.

A lever is basically a bar or a rod that can rotate about a fixed point called a fulcrum. There are three kinds of levers, classified on the basis of the position of the fulcrum with respect to the load and the force applied. The first kind has the fulcrum in the middle and the load and the force at either end, as in a see-saw. In the second kind the fulcrum is at one end while the load is in the middle. An example is the wheelbarrow. In the third kind, the load and the fulcrum are at the ends, while the force is in the middle, e.g. a cricket bat.

A pulley is a machine which is used to change the direction of the force needed to move an object. The simplest form of a pulley is a disc with a rope around it. This is the kind of pulley used to draw water from wells. Nowadays there are many complicated forms of pulleys, but the basic principle remains the same. No one knows who first invented the pulley, but there is evidence that it was used to draw water from wells as early as 1,500 BC.

Huge ramps were used to pull heavy stones for building the pyramids in Egypt. A ramp is an inclined plane that allows one to lift heavy objects with the application of a little force.

The wheel and axle is a simple machine where a rod or axle is attached to the centre of a wheel. Examples of this simple machine are bicycles, cars and even the water tap. The first wheel and axle is believed to have been used in Mesopotamia for carts, about 5,000 years ago.

When we water plants with a pipe, the water takes a curved path before falling to the ground. This is called projectile motion. The same path is taken by a bomb fired from a cannon. For the cannon shot to go the maximum distance, the cannon should be inclined at 45° to the horizontal.

Newton's Law of Gravitation states that 'the force of gravity between any two objects, is inversely proportional to the square of the distance between them'. The Earth's gravity decreases as we go away from the Earth. For instance, an object that weighs one kg on earth would weigh only 250 g if we took it 6,400 km (the radius of the Earth) into space.

But interestingly, as we go down towards the centre of the Earth, the force of gravity decreases till it becomes zero at the centre! If we were to drop a body in a hole dug right through the centre of the Earth to the other side, it would oscillate like a pendulum!

We experience a light feeling in a lift as it goes down. What if the ropes holding the lift broke and it started falling freely? Then we would experience the same kind of weightlessness that astronauts feel in space. A freely falling body is weightless!

Why do you think it is easy to pierce things with a needle but harder to do it with a blunt nail? The answer to this is in the pressure exerted. Pressure is defined as the force that acts on a unit area. A needle, with its fine tip, has more pressure for the same force than a blunt nail that has a larger tip. It is the same principle that is used in tanks and bulldozers where instead of tyres we have tracks so that they don't get stuck in loose mud. Their enormous weight is distributed over a larger area and thus a smaller pressure is exerted on the ground.

Whenever two surfaces are in contact with each other, we get a force that opposes motion and is called friction. In most cases,

friction leads to a loss of energy in the form of heat—the wheels of your cycle feel hot after you have ridden it. But friction has its definite uses too. For instance, it is the friction between our feet and the Earth that enables us to walk without slipping.

A parachutist dropped from an aeroplane experiences a frictional force called atmospheric drag. The parachute increases the drag because of its large area. This allows the parachutist to attain a constant speed of descent called the terminal velocity.

Water droplets are spherical in shape owing to the force of surface tension. Liquids behave as if their surface is covered with a membrane that has a tendency to shrink. This shrinking force tries to reduce the surface area of the liquid as much as possible. Since a sphere has the least surface area for a given volume, the natural shape of liquid drops is spherical.

Surface tension is also responsible for capillary action. The wick in a kerosene lamp, commonly used in

villages, is a piece of cloth dipped in kerosene. The kerosene travels up the wick because of capillary action. The motion of water from the soil to the leaves in a plant is also dependent upon capillary action.

In the 18th century, a Swiss scientist, D Bernoulli discovered that when fluids are in motion, then in regions where the speed is less, the pressure is higher and vice-versa. This important principle is what allows the aeroplane to lift off the ground. The shape of the wings is such that the airflow above them is faster than it is below and hence, the pressure of the air is greater below. This excess pressure forces the plane to take-off.

Liquids and pumps are closely associated. Possibly the most reliable pump is in our own body—the heart! An average human heart beats about 2.8 billion times in our lifetime and pumps 170 million litres of blood.

When a stone is thrown into a pond, waves radiate outward. But in fact, the water only moves up and down. It is the disturbance that moves outward. The motion of the disturbance is called wave motion.

There are two kinds of waves—longitudinal and transverse. In longitudinal waves, like sound waves, the motion of the particles is along the direction of the wave while in transverse waves, like waves on a stretched string, the motion of the particles is in a direction at right angles to the wave direction.

Waves travel at a fixed speed in any given medium. The speed depends only on the nature of the medium. All waves are characterised by a wavelength, the distance between successive crests or troughs (measured in centimetres or metres), and frequency, or the number of waves emitted in unit time. The velocity is always the product of the wavelength and the frequency.

Sound waves are pressure waves. The speed of sound depends on the material in which sound is travelling. For instance, the speed of sound in air under normal conditions is about 330 m/sec while in steel it is about 5 km/sec.

Sound needs a medium to travel in. It cannot travel in a vacuum. Thus, if there was a huge explosion in outer space, we would not hear anything even if we were close to it!

The human ear can only detect sounds which have a frequency between 20/sec to 20,000/sec. Dogs can detect considerably higher frequencies and this is how dog-whistles work. Ultrasound machines use very high frequency sound waves to take images of our bodies.

Light also travels in waves, but these are different from sound waves. Light waves are electromagnetic waves that can travel in a vacuum. Their speed in vacuum is 299,792,458 m/sec! This is why we

see a lightning flash much before we hear the thunder.

The speed of light is not the same in all substances. For instance, the speed of light in water is three-fourths its speed in vacuum. This change in the speed of light causes refraction or bending of light waves in glass and other substances. This is the principle that is used in instruments like microscopes and telescopes and even in spectacles.

Our eyes contain a lens that focuses the light from our surroundings onto a membrane called the retina. This generates a signal that travels to the brain to form the image of the object we are seeing. Our eyes have evolved to work in air and hence, we cannot see very well under water. Some fishes have eyes that have two lenses—one to see under water and another to see in air.

The extent of bending of light in a medium is also dependent upon the wavelength of the light. In case of

white light, which is made up of the seven colours, the blue light (of shorter wavelength) is bent more than the red light. This is how a prism produces a spectrum from white sunlight.

As the white light from the Sun hits the dust and gas particles in our atmosphere, the light is scattered. Different colours are scattered differently with the blue light being scattered the most. This causes the sky to appear blue. In fact, the sky looks completely black on the moon because it has no atmosphere.

In physics, temperatures are usually measured in degrees Kelvin. To convert degrees Kelvin to Centigrade, one only adds 273 to the temperature in Centigrade.

0° Kelvin is the lowest temperature attainable by any substance. In fact, at that temperature, an ideal gas will have zero volume! In reality, most gases liquefy much before this temperature. The lowest liquefying temperature for any gas is 4° Kelvin for helium. Liquid helium is used wherever very low temperatures are required.

Heat always flows from a higher temperature to a lower temperature. Heat flows by conduction in a material that does not move physically, or by convection in fluids where the fluid moves. Convection is what causes hot air to rise in the atmosphere and cold air to settle down. Since both conduction and convection need a medium, thermos flasks have a vacuum between the two walls to minimise loss of heat and keep the liquid contained in the flask hot.

If heat needs a medium to be transported by convection and conduction, how is it that we get heat from the Sun? This is because heat can also be transferred by radiation without any medium. The walls of the thermos flask are made of reflecting glass to minimise radiation.

When we heat water, its temperature keeps rising till it begins to boil at the fixed temperature of 100°C. If we continue heating the water, the

temperature will stay at 100°C while the water will begin to turn into steam. This heat that is needed to transform a liquid into vapour is called latent heat. Water has very high latent heat and that is why when our sweat dries (or evaporates into vapour) it takes heat from our body, cooling it in the process.

Our bodies lose heat to the environment in the winter because of the temperature difference. A woollen sweater keeps us warm because it traps air between its wool fibres and thus does not allow convection to take place.

Iron is attracted to a magnet. Materials like iron, which retain some of the magnetism even after the magnet is removed, are called ferromagnetic materials. If these are heated to high temperatures, they lose their magnetic properties. The temperature at which this happens is called the Curie temperature and is about 770°C for iron.

Some substances like bismuth are repelled by magnets—these are called diamagnetic substances.

After a plastic comb has been rubbed on cloth it can pick up small pieces of paper. About 2,500 years ago, the early Greeks observed that when amber was rubbed, it attracted light objects. We now know that the process of rubbing makes the comb electrically charged. In fact, the word electricity comes from the Greek word *elektron* which means amber!

When clouds come together, they produce electricity, which in turn causes lightning. Lightning flashes travel at a fantastic speed of over 2,500 km/sec and can be over 30 km long!

A typical lightning bolt can have a temperature of over 30,000°C and can discharge 5,000 megawatts of energy! But since it lasts only for about a thousandth of a second, the total kilowatt hours (units that you pay for in your electricity bill) is only about 1,500 kilowatt-hours!

The lightning bolt heats the air along its path and this causes the air to expand at a very rapid rate. The expanding air causes the vibrations that we hear as thunder.

Electrons can flow easily through some substances called conductors. Most metals are good conductors of electricity. Most non-metals are bad conductors and are called insulators. Conductors are said to have low electrical resistance as compared to insulators. Electricians sometimes wear rubber gloves to protect themselves because rubber is one of the best insulators.

When the two terminals of a battery are connected through a wire, electrons flow from the negative terminal to the positive one causing an electric current. Such a current is called direct current (DC) and it flows in one direction. The rate of flow of electrons or current depends on the voltage of the battery (measured in volts) and the resistance of the wire.

Alternating current (AC), where the flow of electrons changes direction, is the form of electric current generally used in India. When the voltage is 220 V, the current alternates at least a 100 times a second.

Electricity is produced by huge generators that run on burning coal or gas, using the flow of rivers or even on nuclear energy. Electricity is then transported across the electricity grid at very high voltages, sometimes as high as 2,20,000 volts! This is then brought down in various stages so that ultimately we get 220 V at our house.

Electricity travels at roughly the speed of light. Thus, when the generator at Bhakra is switched on, the lights in Delhi (a distance of about 500 km) light up in less than a thousandth of a second!

Electric current produces heat. The amount of heat produced depends on the current and the electrical

resistance of the material through which the current passes. The electric fuse works on this principle. The fuse wire is made of a material with a low melting point. If the current is too high, the heat produced melts the wire and disconnects the circuit.

Electric current creates a magnetic field. Overhead power cables, computers, microwaves—wherever there is electricity, there will be a magnetic field.

An electromagnet can be created by passing an electric current through an iron nail. The greater the electric current, the more powerful the magnet will be. Electromagnets have several uses. For instance, they are used to pick up hot iron bars in steel plants.

In our body, electricity plays a very crucial role. Our nervous system depends on electric signals transmitted to and from the brain and the spinal cord. Most nerve signals travel at the rate of about

1 m/sec but in some nerves this speed can be as much as 100 m/sec. Electrical impulses are also produced in our muscles including in the heart muscles.

Physics at Work

The computer monitor and the television screen both work on the basis of a device called the cathode ray tube. In this, a heated filament gives off electrons. These electrons travel towards a screen that is coated with a phosphorescent material. The electron path can be controlled by electromagnetic field. The point where an electron hits the screen glows and a combination of such bright and dark spots gives us the image.

W Roentgen accidentally discovered X-rays in 1895. The electrons produced in a cathode ray tube are accelerated to very high speeds before they are made to hit a target to produce X-rays. Apart from being immensely useful in medicine, X-rays are also very useful for scientists to study metals and materials. Too much exposure to X-rays can lead to cancer. Lead and other heavy metals are useful to stop X-rays. Therefore, doctors operating X-ray machines wear heavy coats with lead shields.

Computerised Axial Tomography or CAT scans are now routinely used by doctors to get better images of the human body. A CAT scan machine has many X-ray generators that bombard the body from different angles. All these images are then processed by a computer to form a composite image of the body.

Though radioactive radiation is harmful to living things, doctors use it to treat cancer. A small amount of radioactive material (usually cobalt) which emits gamma rays is used in radiation therapy for cancer patients. The gamma rays are made to hit the cancerous tumour and destroy it. Unfortunately, these rays can also harm the other healthy cells in the neighbourhood of the tumour.

The heart muscle generates electrical impulses which can be recorded using an Electro Cardiograph (ECG). The shape and size of the electrical impulses reveal the condition of the heart muscle and allow the doctor

to identify problems, if any, with the heart.

The microphone that is used to amplify a person's voice is based on the principle of electromagnetism. The sound energy in the voice makes a plate vibrate, which determines how much current flows in a circuit. This current can then be fed into a speaker where it operates an electromagnet. The variations in the current produce a varying magnetic field that vibrates a plate to produce sound.

The telephone was invented by Alexander Graham Bell in 1876. The telephone converts the sound energy of the voice into electrical energy in the mouthpiece. This electric signal is then transmitted to the receiver. In the receiver earpiece, the electrical signals are reconverted to the sound we hear.

Cellular telephones are basically radio receivers and transmitters. The handset communicates with the base station (the huge red-coloured masts that you see on top of buildings)

using microwave frequencies (about 2 billion cycles per second). A combination of sophisticated electronics and software allows you to talk even while on the move.

In present times, most telephone traffic moves through fibre optic cables rather than copper wires. These are ultra-thin 'wires' made from a special kind of glass that can carry light. The electrical signals are converted into light signals and then sent through these glass fibres. The glass is so made that light stays within the fibre for several kilometres. This is achieved by reflection of the light from the walls of the fibre.

The property of certain materials to magnetise and demagnetise easily is used in many devices. In an audio tape, the magnetic particles on the tape are aligned magnetically due to the magnetic force of the recording head. As in the telephone mouthpiece, in the audiotape too the electric current supplied by the microphone determines the magnetic force of the head.

Magnetic materials are used to make computer hard discs. Regions on the hard disc or computer memory are magnetised in one direction or the other, thereby allowing it to store information. Like all information in a computer, this too is stored in binary form, that is, in a sequence of 0s and 1s.

Digital cameras are now fast replacing old-fashioned cameras. Light entering a digital camera falls on a chip that has many tiny cells. Each cell responds to the light falling on it to produce an electrical signal. The combination of all the signals is the image that is stored on a memory chip and can be viewed or even printed like ordinary pictures.

Can you imagine travelling from Delhi to Mumbai on a train that moves at an unimaginable speed of 450 km/hr? Magnetically levitated trains, that are now in use in many cities around the world, have huge magnets on them that create a force between the magnets and the metal rails. This force not only propels the

trains to high speeds but also lifts the train a short distance above the tracks. So, in effect, the train does not move on the track but is suspended in air! These trains are called maglevs or magnetically levitated trains. Such trains have been operational in Shanghai since December 2002.

Unlike an aeroplane, a helicopter, can take off and land vertically. It produces the upward force with the help of its rotors which create an airflow above the helicopter. This provides the lift. The wings of an aeroplane serve the same purpose. The aeroplane gathers speed on the runway, the airflow along the wing surface provides the lift necessary for take-off.

Rocket engines that power spaceships and missiles work on the principle of action and reaction. Solid or liquid propellant fuel is burnt and escapes from the rear of the rocket engine at huge speeds (upto 5,000 m/sec in some rockets). This provides a reaction that pushes

the rocket forward and allows it to attain the speed needed to escape the Earth's gravitational force.

Automobiles of the future could well be running on fuel cells. Fuel cells produce electricity directly from a chemical reaction. The most promising is the hydrogen fuel cell, where hydrogen is used as a fuel to produce an electric current to run the car engine. The waste product of such a cell is water formed when the waste hydrogen combines with oxygen from the air. Some prototypes of such cells are already in use in the US.

The huge electromagnets in maglevs and in particle accelerators are superconductors. Super-conductivity is a phenomenon where certain substances lose all resistance to electric current at very low temperatures. The advantage of superconducting magnets is that there is no loss of energy as heat. The heat generated depends on the resistance of the wire which in this case is zero.

The refrigerator has a refrigerant placed in a sealed system. The refrigerant evaporates into a gas thereby cooling the inside of the refrigerator and then condenses back into a liquid. Heat is generated when the gas condenses back into a liquid. This heat escapes through the metal fins placed on the refrigerator and makes the back of the fridge warm. The whole process requires a compressor to compress the gas.

The microwave oven uses microwaves generated by a device called a magnetron. These microwaves get absorbed by the water molecules in the food and thus heat the food. A metal dish should never be placed inside a microwave oven because it can become dangerously hot.