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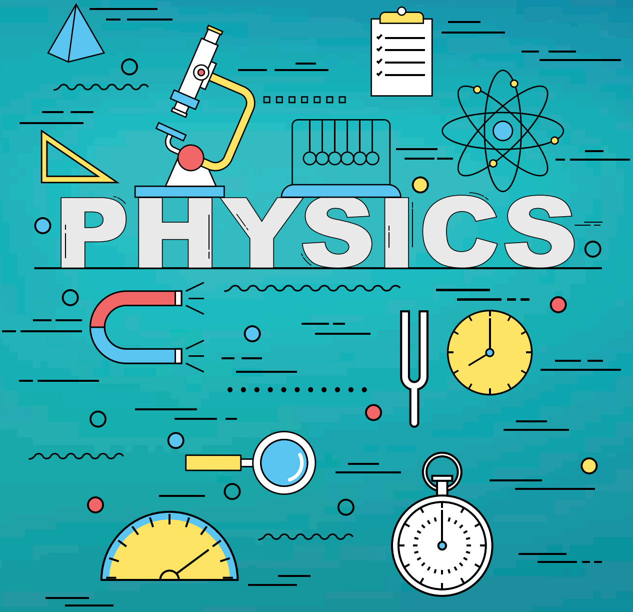
The Small Book of Big Thoughts



THE STUDY OF STUFF

digit

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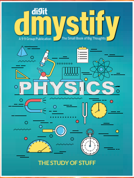
April 2019

How stuff works

And why stuff works

INSIDE



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The study of everything!

Physicists are sometimes considered to be the most irritating know-it-alls, because they truly believe that their discipline of study is all encompassing. The problem is, being insufferable egomaniacs does not make them wrong. After all, if physics is the study of nature and the universe, it is kind of all-encompassing. There's nothing we study that is out of this universe, and perhaps may never be anything we study that qualifies as that.

From the beginning of the universe at the Big Bang, to the eventual death of the universe, and everything in between it's all physics. Not just that, but from the study of the universe right down to the study of the quantum world, all that's physics as well. It's the oldest science, and that's why it's the first we cover. Some consider Chemistry and Biology to just be off-shoots of Physics that have become sciences on their own.

We've already covered math in a dmystify – more as an abstract concept as the language of the universe than a hard science. Thus, when we decided to cover the 'hard sciences' as topics in themselves, we had to start with the most important of them all. Keep an eye out for Chemistry and Biology in coming months. ■

The ancients

A little history lesson

Although we have no written records or proof of what prehistoric man studied, anyone who has spent a night in an area that isn't light polluted will agree, the oldest fascination of man must have been the night sky. While the day time was filled with things to do, at night, humans would have been awed by the sheer beauty of the night sky. In fact, astronomy has to be amongst the oldest known disciplines that was common across the world – no matter which civilisation and at which time in history, all human groups have an astronomical history. Even Australian Aboriginals, who were isolated from the rest of the world for tens of thousands of years in prehistory, have stories that are related to constellations, stars, planets and the sun and moon. They're considered to be the oldest known civilisation based on archaeology and DNA tests.

Of course, there was a lot of superstition and mythology in prehistory, in almost all cultures across the globe. This was because when one knows nothing about stars or what they are, and has no concept of the relation between distance and size, one comes up with supernatural ideas to explain things away. And how very creative some of those stories are... However, for this book we're going to stick to the pure science of it all.

Prehistory

Almost all of prehistoric physics is thought to have been amateur astronomy. Although the stars and planets may have been given different mythologies by different civilisations, there is no doubt that many such civilisations noticed the difference between the fixed stars and the roving planets. In fact, there is a complete field of study, called archaeoastronomy that looks at all that ancient man knew about astronomy and how they went about using it for religious or practical reasons.

In essence, the earliest study of physics (in this case astronomy) was to identify patterns – something humans are particularly good at. It was beneficial to know patterns of stars, as identifying them in the sky meant that you could expect certain things. If you wanted to know how many hours until the sun rose again, studying the stars could tell you. Same for what time of the year it was (before calendars), because knowing which month to sow the crops in was very beneficial. And, of course, there was always a question of which way to travel at night – the fixed stars can be used to find directions, and are especially useful when you're at sea.

Archaeoastronomy

There's actually a little bit of a debate around the term archaeoastronomy. Some believe that since modern astronomy is absolutely nothing like what astronomy was in ancient times, it's basically a misnomer. This is because astronomy was more religious or cultural in ancient times rather than a scientific endeavour. Of course the other side of the debate says that everything was more simple and more cultural and religious for the ancients However, would the invention of the wheel be any less a scientific achievement had it been discovered whilst making statues of a circular god?

Now, whether you consider archeoastronomy to be more scientific or more anthropological, it's still important to understand the earliest human understanding of basic physics. Obviously, because we're including archaeoastronomy in this book, we consider it to be the beginnings of scientific thinking.

Stonehenge

A prehistoric site of great interest to archaeoastronomers, Stonehenge was probably a religiously significant site for ancient people from as early as 8,000 BC (or over 10,000 years ago!). The structure that survives to modern times was built much later, between 3000 and 2000 BC. However, excavations have shown that there was activity, construction and burials happening at the spot for at least 5000 years prior to that.

The astronomical significance of Stonehenge is essentially unknown, as it is from a time that predates written language, but modern astronomers and scientists believe it was essentially a way of tracking the winter and summer solstices. Some even believe it to be the world's first sundial, but that is a disputed theory. The fact is that we just don't know for sure what people were doing and why

There is certainly some astronomical significance of stonehenge, we just don't know for sure what it was

they built this large structure at so much cost in terms of manpower and time. The fact that the sunset of the winter equinox and the sunrise of the summer equinox seem to line up perfectly with the way Stonehenge faces seems to indicate it was certainly designed with at least basic astronomy in mind.

Pyramids of Giza

We've all heard about the three great pyramids being lined up in size and position to match three stars in what's known as the constellation Orion now – the three stars that make up Orion's belt. This is a

The Egyptians were surprisingly good astronomers, but did that play a role in the design or construction of the pyramids?

much disputed theory, and one that is actually falling out of favour with the majority of scientists who research the field. However, there is also evidence to show that the pyramids were also constructed with the solstices in mind.

Prehistoric India

In our mythology, there are plenty of references to astronomical events. Things such as solstices and eclipses were noticed by ancient Indians, and inventive stories were written around them. For example, the demon planets Rahu and Ketu are supposed to be the reason solar and lunar eclipses occur. Rahu and Ketu are thought to be two parts of a demon's body that was beheaded by Lord Vishnu – Rahu is the head, and Ketu is the tail or the body. Since both the tail and the body are separated, both have openings on both sides, and therefore when Rahu tries to eat the sun (a solar eclipse occurs), it soon appears again.

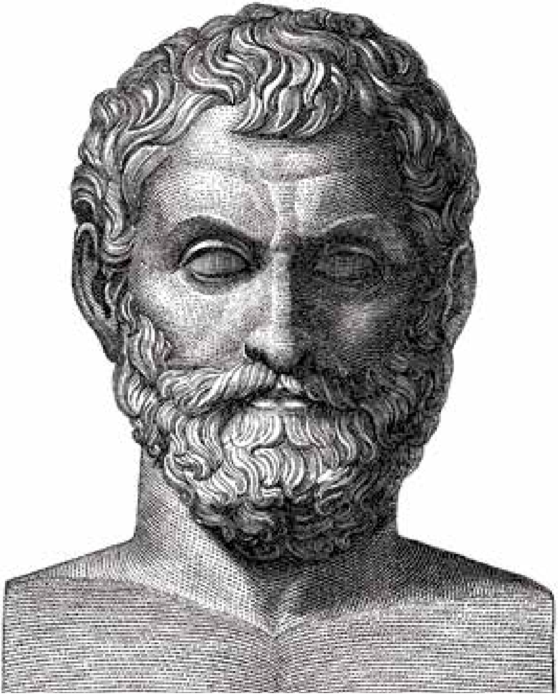
Sadly, we do not have time and space to go into all archaeoastronomical claims as that's beyond the scope of this book, but we encourage you to read more about the topic on your own. Now it's time to fast forward to more modern times:

The Ancients

Scientific thinking was alive and well as much as 6,000 years ago, and we have evidence of this in various forms. Every civilisation has some story to tell, and the lines often blur the further back we go, because it's hard to tell which civilisation invented something, because good ideas spread pretty quickly. For example, there are many who believe that cataract surgery was started in India and exported to China, while there are those in China who believe the opposite. With a lack of written documentation from the ancients, it often boils down to just accepting the evidence we have for a lot of things, and acknowledging that new evidence can change the accepted history in a flash.

Greeks

As usual, because of their immaculate record keeping, the Greeks are the ones whose scientific studies we know the most about. In fact, the term Physics comes from the ancient Greek word "Physis" which means "nature". It was about 650 BC when the Greeks started looking into a more modern and scientific understanding of nature. Sometime in the seventh century BC, Thales of Miletus (also known as the 'father of science') made one of the most important statements ever made by a human! He was the first to proclaim that every event had a natural cause, and refused to believe that religious teachers could offer any insight into how nature actually functioned. Between the seventh and first century BC, the Greeks made some astonishingly accurate (for the time) observations.



Thales of Miletus (lived 624/623 to 548/545 BC)

Thales was a philosopher, but also indulged in scientific experimentation and methodological notation. He experimented with magnetism and static electricity (without knowing what they were or why they were caused), and also came up with ideas about the origins of the universe. He was wrong, because he thought everything was made from water, but he was one of the first Greeks to come up with a hypothesis about the nature of matter.

Aristarchus of Samos was one of the first to place the Sun at the centre of the universe, and to suggest that the Earth revolves around the Sun. Seleucus, a student of his, would go on to assert that the Earth also rotated around an axis while it was revolving around the Sun. He did it using logic, and was something that would only be proved centuries later. Sadly, it was all forgotten and the geocentric (Earth at the centre) idea was most widely accepted.

Then there were giants like Archimedes, who was considered to be one of the greatest of all ancient mathematicians, and developed what we know today as Archimedes' principle, which we all still study in school. He also calculated the area under a parabolic curve using mathematics, and his approximation was very close to the actual value of pi.

There are many more we cannot delve into detail about due to lack of space, such as Aristotle, Hipparchus, Anaximander, Leucippus, Eratosthenes, Ptolemy, and more...

Plato (L) and Aristotle (R) as depicted in Raphael's 1509 fresco titled The School of Athens

Indians

The Indus valley civilisation was credited with inventing the practice of irrigation of crops and water storage, as far back as 4500 BC. Irrigation led to a hugely prosperous civilisation, which then went on to invent sewerage – very important when you have thousands of people living in close proximity. The Indus Valley Civilisation

Mohenjodaro: The stupa mound and the great bath shown here

also developed more firsts, such as standardisation of weights and measures in order to enable trade, and also precise tools to measure angles, lengths, and more, which were used not just in trade but also in the construction of their houses.

It's not just all about farming, because ovens and kilns that date back to over 5,000 years have been discovered that are thought to have been used to produce ceramics. Copper and bronze swords have been discovered that were dated to 2500 BCE! There is evidence of animals being used to plough fields, and our mathematics of the time was by far the most advanced. The vedas regularly deal with numbers in the trillions when most of the world was still counting on its fingers.

Ayurveda was one of the most advanced medical compilations of the ancient world, and it is still in use today. As early as 600 BC there is evidence of cataract surgery being performed in India, with pretty decent success, as mentioned in the Sushruta Samhita. The Samhita also contains descriptions of treatments for over 1100 illnesses. Of course, the Sushruta Samhita is merely a compilation of ancient wisdom from around ancient India, and there is evidence in the Atharva-veda from 1500 BC that some of this was known back then as well.

Classical physics

We could probably fill 100 books of this size if we wanted to go really indepth into the history of scientific discovery from all the civilisations and areas of the world, because there is just that much history. However, we have to race through the achievements of man, and skip some very, very important names because we don't want this book to just be a history lesson.

From the ancients we're fast forwarding to more modern times, and landing straight in the 16th and 17th centuries (between 1500 and 1600). This is because most of what we consider to be classical physics was done in this period and since then.

Because the Europeans are the ones who essentially conquered the globe, it is through an European lens that we have to look at history, and it is Europe that is credited for most modern scientific ideas, rightly in some cases and wrongly in others. Either way, it was the Scientific revolution of the 1600s that essentially moved us away from the hold that European religious institutions had on the scientific discourse of the time.

As we've mentioned earlier, the idea of heliocentrism (Sun at the centre of the solar system) was not new, and even the ancient Greeks had dabbled with the idea. It was Nicolaus Copernicus, just before he died in 1543, who brought up the idea of heliocentrism again when he published "On the Revolutions of the Celestial Spheres" in 1543.

Later Galileo Galilei would use Copernicus' theory to develop his own theories and also would use experimental data and telescopes to further the theory of heliocentrism. Being Italian and much closer to the church than others, he was made an example of in 1633, and forced to recant his theory and placed under house arrest for the rest of his life.

Much later, in 1687 Newton would publish Mathematical Principles of Natural Philosophy (also known as Newton's Principia), which would, amongst other things, prove Kepler's laws of motions of the planets to be correct. He effectively killed off the idea of geocentrism.

After Newton, thanks in part to calculus that was created by Newton and also independently by Leibniz, classical physics really took off. It became mathematically possible to calculate complex problems, which could then be matched with experimental data. It was in this time after Newton that mechanics and thermodynamics took off. Swiss mathematician Daniel Bernoulli would use mathematics to study gases and fluids, or what is called fluid mechanics today. His studies resulted in what we call Bernoulli's Principle today, which is what we use to understand airflow, and essentially is the principle around which aircraft are designed.

In 1800 Allesandro Volta invented the electric battery, which would go on to change the world we knew, because electricity could now be stored. In 1821 Michael Faraday would build an electric motor, and a decade later in 1831 he would discover the relationship with electricity and magnetism, which we know today as electromagnetic induction. These are the stepping stones to the construction of the electric motors and generators that we use today.

In 1859 James Clerk Maxwell showed that light was just another electromagnetic radiation, and the wave theory of light gained more

Allesandro Volta invented the electric battery, and single-handedly revolutionised the world

acceptance. In the 1890s Guglielmo Marconi developed a system that we would eventually call the radio, and a new age of information flow was born.

Modern Physics

Fast forwarding to the 20th century, it was the work of Marie Curie that would challenge the idea of the atom being indestructible. Henri Becquerel, J J Thompson, Ernest Rutherford, Albert Michelson and Edward Morley, and others, would all work towards understanding radiation and the basic structure of matter.

Albert Einstein would rock the world with his theory of space-time and mass-energy equivalence. His work on special relativity and general relativity would revolutionise the entire field of physics.

Niels Bohr, Max Planck and Werner Heisenberg and many others would go on to make significant contributions to what would eventually become the field of quantum theory. Richard Feynman would then make significant contributions to quantum electrodynamics, and then the age of particle colliders would be born. All culminating in the Large Hadron Collider at CERN which we wrote an entire dmystify about last year!

As Newton famously said, "If I have seen further than others, it is by standing upon the shoulders of giants." And that is modern science in a nutshell. Slow and gradual increments of knowledge, based on painstaking work done by yourself, which is in turn based on painstaking work done by others before you. It's why we love science so much, and why the scientific method is the only method we know of arriving at objective truths about the natural world. ■

Areas of study

We look at what physics is studying and how it is divided up

Much of classical physics was done between the 1600s and the 1900s, and there were those who assumed that we'd know everything and have solved everything by the 21st century. Of course, as we sit here today in the 21st century, we know that nothing is further from the truth. In fact, the more answers we get, the more questions seem to be raised, and it may be far more likely to assume that our learning will never be done, not even as long as the human race exists – for however long or short a time you can imagine that to be.

While classical physics dealt with simpler, more visible effects of nature around us, modern physics is pushing the boundaries far beyond our rather limited capabilities of experience. We can only see a very narrow band of electromagnetic radiation, for instance, and it is the study of EM radiation far beyond what our eyes are capable of perceiving that has led to most of the revelations of modern physics. Whether it's studying microwave radiation from the universe, or X-rays from distant objects, and more recently, gravitational waves from distant black holes colliding, we have gone so far beyond human capability that not only do we need machines to observe our experiments, but we need machines to even conduct them. If AI is ever realised, we can even replace ourselves and have it do the only real job we have, which is to interpret the results of the experiments.

Classical physics deals with things that are bigger than an atom, and moving at speeds far, far slower than the speed of light. The minute we break down an atom and start approaching even fractions of the speed of light, classical physics breaks down and is unable to correctly predict anything. In terms of very high speeds Einsteinian physics comes in and explains things by introducing the concept of relativity. On the other end of the scale, at sizes much smaller than an atom, quantum theory comes in and describes what we see when we try and do experiments.

Theoretical vs Experimental

At the most basic level, modern physics is divided into theoretical and experimental physics. This really is an artificial division, because each subset of physics can have both theoretical and experimental aspects. For example, in cosmology, ideas like the

Big Bang can be arrived at using both theoretical math as well as confirmed using experiments. In many ways, theoretical physics is only theoretical because we haven't figured out a way to do the experiments just yet.

All of theoretical physics is done using complex mathematical models and abstractions in order to formulate theories that can explain what we observe in nature, or to predict what we haven't yet seen in nature. Theoretical physics is almost purely mathematical, and is impossible to do without a deep, deep understanding of the most complex mathematics known to mankind. Einstein was a theoretical physicist, and is one of the most famous people on the planet because his theories were consistently proven right by experimental physicists, and he continues to be proven right even today. His grasp of mathematics, in conjunction with a healthy imagination and ability to think in the abstract is something that the world had not seen before, and in truth, is something that has never been seen since.

Applied Physics

This is a branch of physics that is basically a bridge between physics and engineering. The idea here is that applied physics is used for more practical applications, and is usually to do with technological advancement. Unlike engineering, which is divided up by branches of specialisation and focus, applied physics is not specialised to engineering fields. Instead, an applied physicist can conduct research without the aim of designing something in particular, which is the opposite of what an engineer does. The sole aim of an applied physicist is to conduct research in physics that can be used by others in various fields to advance their own field.

Transistor

One of the most important devices ever to come out of an applied physics laboratory was the transistor, without with no technology would exist. It is easily the greatest invention of the twentieth century. While vacuum tubes were used prior to transistors to perform similar tasks, the amount of energy they needed in order to run made them prohibitive. Once the transistor came along, we had an easy way in which to amplify signals, and more importantly, had a way in which to create automated switches. Semiconductors and the doping of silicon to make it more conductive was all worked out in an applied physics lab. The transistor was born in Bell labs but was based on ideas and patents by other scientists in the field. Julius Edgar Lilienfeld, an Austrian physicist working in Canada is credited with first patenting the transistor design in 1925. However, because he didn't publish research articles, and because of World War II, his contributions were all but forgotten. Bell labs takes credit

What the first working transistor would have looked like. Now they're built at a nanoscale level!

for making the first working transistor, naming it "transistor", and also for making the first silicon-based transistor. Three scientists working there, John Barden, Walter Brattain and William Shockley were awarded the Nobel Prize for it in 1956.

Laser

It was actually Einstein that came up with the basic idea of Lasers and Masers in his paper titled "On the Quantum theory of Radiation" in 1917. Much later, in 1959 Gordon Gould would publish a paper titled "The LASER, Light Amplification by Stimulated Emission of Radiation", which would outline his idea on how a LASER could be used. It wasn't until 1960 that the first Laser was operated by Theodore Maiman at Hughes Research Labs.

Others

In addition to these two inventions, there are hundreds more that came out of the applied physics labs across the world. These include microscopes (scanning and electron versions), semiconductors, radar, sonar, lidar, stealth technology, all the stuff used to build the various colliders around the globe, pretty much all nuclear engineering (from bombs to reactors for power plants), GPS satellites, modern electronics, WiFi... and many, many more things we all take for granted. Applied physics is what most of us reap the benefits of in everyday life. The entire technological revolution that we all know and love all stem from this field, and chances are, if you work in the field of technology for a large corporate company, they have an R&D division that's dedicated to researching applied physics.

Astrophysics

This is a branch of astronomy that uses the principles of both physics and chemistry to try and figure out what distant "stuff" is made of, how it behaves, and also more abstract concepts such as whether time travel is possible, or whether wormholes can exist.

It's the rockstar of physics these days, with more time on TV and social media devoted to the findings of astrophysicists than any

Sagan: The man who popularised physics for the masses

other discipline. This is because we love learning about space and distant galaxies, and so we gobble up content based on astrophysics with delight.

Astrophysics is pretty all encompassing when it comes to space, and thus it's broken up into sub-disciplines:

Observational

Almost all observational astrophysics deals with experiments and observations using the electromagnetic spectrum. This is because we really don't know too many other ways in which to look at the universe. Almost everything we have discovered about our universe is thanks to observational astrophysics, and the electromagnetic spectrum. A few examples of observational astrophysics that don't use the electromagnetic spectrum are studies done to discover gravitational waves, and the attempt to study neutrinos. We haven't had too much success with either gravitational waves or neutrinos when compared to electromagnetic studies, but this is because our equipment and capabilities are still limited. As we get more sophisticated equipment that's capable of measuring finer margins, we will do much more than merely discover gravitational waves or catch the odd neutrino, and instead will be able to study them in much more detail, and this will reveal far more than the electromagnetic spectrum has shown us thus far.

Theoretical

Theoretical astrophysics is really where all the stars (as in popular humans) are working. Most of the physicists you see on TV talking about string theory, or M-theory, dark matter and dark energy, inflation, and all of the buzzwords we associate with the cutting-edge of physics... all of that is theoretical astrophysics. Of course many famous physicists are multi-talented, for example Carl Sagan was an astronomer, astrophysicist, cosmologist and astrobiologist all rolled into one extremely awesome human. (In case you hadn't noticed, this writer is a fan of Sagan).

Theoretical astrophysicists use mostly analytical models and advanced mathematics to try and find interesting answers to questions, or sometimes to find interesting questions themselves. Einstein was perhaps the most famous, followed closely by Stephen Hawking, and both are being proved right about so many things even after they're dead. Gravitational waves are what popped out at the world of physicists from Einstein's equations, and he was proven right about them. Hawking was famous for figuring out that some things do indeed escape black holes (called Hawking radiation), but most of us know him from his appearances on TV shows like the Simpsons and the Big Bang Theory.

Currently, our best bet at being able to travel faster than the speed of light across the vastness of space-time is by using wormholes, which are a theoretical astrophysics concept that are yet to be proven or disproven. If we're ever going to conquer intergalactic travel in acceptable time periods, it will be theoretical physicists who come upon the way to do it.

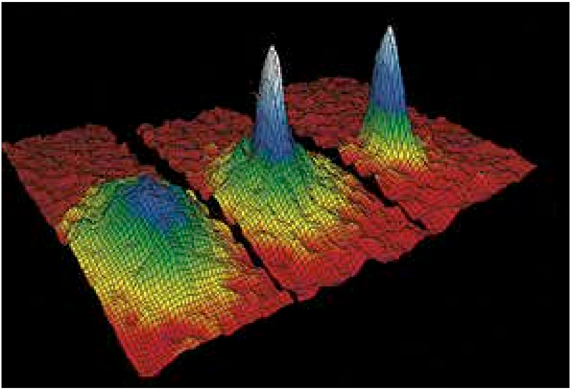
Atomic and molecular studies

Atomic physics is very closely tied in with Chemistry, and studies the physical nature of atoms, compounds and molecules. The study of the atom these days has to include quantum mechanics, as well as studying the behaviour of electrons, or rather their probability fields. Because the subjects of the study are so tiny, there is a lot of spectroscopy that is done in this field – measuring and calculating and interpreting tiny amounts of electromagnetic radiation that is either emitted or absorbed by atoms when subjected to various experiments.

The field also studies the behaviour of ions and charged particles and electrons, and all of the associated physics. Studying the ways in which electrons jump states, and the various electron shell configurations are what led to the Bohr model of the atom, and what eventually led to the study of quantum mechanics.

The sophistication of laser technology was a big shot in the arm for atomic physics, as the precision of wavelengths and frequencies that lasers offer allows atomic physicists to measure the interaction with atoms of different elements.

The field also gives rise to things such as more and more precise atomic clocks, more precise measurements of length using light frequencies, and is seen to be increasing the sophistication of instruments across the board. Atomic physics also covers experimentation in creating new forms of matter, such as Bose-Einstein condensates, and other superfluids. A Bose-Einstein Condensate is essentially a superfluid in which all atoms of the gas behave as one, and have the same quantum state. This means that they stop behaving the way



A depiction of a Bose-Einstein condensate of rubidium atoms cooled to nearly absolute zero.

individual atoms do in a gas (brownian motion) and instead, can be thought to be moving much in the way a very large school of fish do. Although not yet worked out in practice, a byproduct of such a superfluid could mean the invention of something called an atomic laser – instead of photons being aligned perfectly as in a laser, imagine a steam of atoms aligned with precision. Think nanotechnology printers that could print precise patterns with single atoms...

Condensed Matter

An offshoot of sorts from Atomic physics, or perhaps even a subset, condensed matter physics looks at the physical properties of matter from the macroscopic level all the way down to the atomic level. The goal is to not just study nature, but to play with various combinations of elements and compounds to come up with materials with interesting properties. From liquid crystals to Bose-Einstein condensates, and from various plastics to other composites that are being used in everything from coating your frying pans to coating NASAs space vehicles, it all falls under this category.

This branch of physics pushes the envelope on pretty much everything, and is usually split into hard and soft condensed matter physics. Here hard and soft are sort of descriptions of textures, but are more accurately the description of the math skills required in each field. Hard condensed matter physics deals with matter that relies on the effects of quantum mechanics, while soft condensed matter physics deals with materials that do not need quantum mechanical effects to be taken into consideration. Examples of materials worked on by hard condensed matter physicists include crystals, various types of glass, metals, insulators and semiconductors. Examples of soft condensed matter materials would include superfluids, liquids, gels, foams, colloids, some polymers and even biological materials.

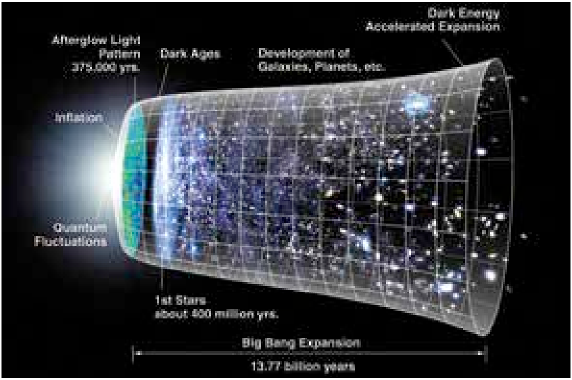
Soft condensed matter physics is all the rage because of their uses in all of the things that are popular. To start with, screen technology depends heavily on improvements in manufacturing of liquid crystal displays. In addition there are applications in packing material, detergents, cosmetics, adhesives, lubricants, fuels, rubber for tyres, and even biological studies on blood and milk, as well as food industry studies with milk, food dyes, etc. You name the field, and you can bet that there are entire research labs of condensed matter physics that are working on improving something in that field.

It's not all practical application though, and there is plenty of theoretical research being done in condensed matter physics. Most important of all is perhaps the high-temperature superconductivity studies that are considered the holy grail of electronics research.

Cosmology

This is a branch of physics that is dedicated to studying the origins of the universe. While astronomy can involve looking at the stars to classify them, and astrophysics can try and see what stuff they're made of and perhaps physics in general can try and work out how it is we can try and get there... cosmology merely wants to know when a star formed, how, and how does it fit into the grand scheme of things... how can it help us understand the origins of the universe.

It's not just the origin story that's important, but also the future predictions of where we're headed, and possibly how the universe



The Big Bang timeline

will finally end. How will the universe change? Will the laws of physics change in the future? Do the laws of physics break down at various places in the universe? These and many more questions are what cosmology seeks to answer.

The Big Bang is the origin story of the universe that cosmologists accept currently, though even that has its problems. We've modified it and added inflationary theory to the mix in order to solve certain problems, but in no way are cosmologists certain that they have the exact picture of the origins of our universe.

Cosmology is the subset of physics that attracts not just pure scientists, but also philosophers and metaphysicians, as the origin of the universe is of interest to us all. However, this also gives rise to some theories that can be tested and some that cannot, because the nature of the theory may or may not be based in scientific reasoning and practice. Of course, we only consider the hard science-based physicists as cosmologists, but that doesn't stop many others who are religious cosmologists or philosophical cosmologists from attaching the title to their names.

Many consider cosmology to essentially be a subset of history, as theoretical astrophysicist David Spergel once said, "Cosmology is a historical science, because when we look out in space we look back in time." Because the speed of light is finite, and the distances in space so large, we're looking at everything in space as it was in the past. Even our own star, the sun, is something we see as 8 minutes in the past, and that goes all the way back to the cosmic microwave background radiation, about 13.7 billion years ago.

Electromagnetism

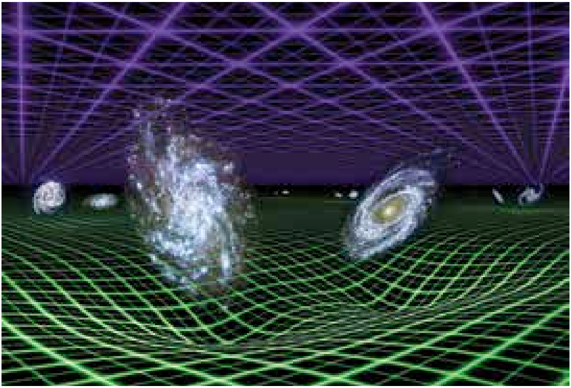
As the name implies, this is the branch of physics that studies electricity and magnetism. The electromagnetic force is a physical interaction between electrically charged particles and it creates electric and magnetic fields, as well as light, and is one of the four fundamental forces of nature (that we know of). The other three forces are gravity, the strong nuclear force (which is a very strong force that acts at very small distances, such as at the atomic level, and holds the components of atoms and molecules together), and the weak nuclear force (which also works at atomic distances, but is far weaker, and is responsible for nuclear fission).

The study of electromagnetism is well understood, however, with the advent of the technology revolution, the challenges to making things smaller yet more powerful has driven research in this field. Add to this the need for faster and better wireless technology such as 5G (or even 6G) and you realise exactly how important this field is and how much work is being done. Of course classical electromagnetism is applied in a myriad of things – all motors and generators, transformers, speakers and headphones, MRI machines, the fans we rely on so much, and many, many more.

In the technology world, pretty much all the trillions of GBs of data we store and send across the world are basically just 1s and 0s that are signified by the presence or absence of electromagnetism in some form. Even when we use fibre optics, because light is essentially just another electromagnetic field that we call radiation, it's really the base of our entire civilisation. It's the fundamental force we interact with most often, or rather are most conscious of, even more so than gravity.

Gravity

One would think that the study of gravity would be changed to the general theory of relativity after Einstein, but it is a really complex theory and has some formidable math associated with it. In contrast, Newton's classic theory of gravitation works perfectly fine, to a degree of accuracy that's actually good enough for NASA and other space exploration programs to use to this day, when we send stuff into space or try and send stuff out to far away bodies in our solar system. Because relativity deals with differences in speeds at the scale of the speed of light, and we really don't have anything that can even begin to approach a fraction of that speed, we just don't need general relativity except for some very rare circumstances. An example is the GPS satellite network, in which satellites are whizzing by in space (relative to a point on the earth) at about 14,000 kmph. Special Relativity results in a mere 7200 nanoseconds a day of difference between time experienced on earth and that experienced on the satellite. Thus, a clock on the satellite is ticking slower than one on earth by about 0.0000072 seconds a day. That's about 0.002628 seconds slower a year. Essentially, it would take about 380 years before the satellite's clock was 1 second slower than a clock on earth. A ridiculously small time difference, right? If you expect us to say "wrong" here, you'd be wrong. That is a ridiculously small difference that could be adjusted for pretty easily.



Source: NASA/JPL

How spacetime is bent because of massive masses.

The problem is, that's just special relativity – the difference in time perceived by two objects moving at speeds in relation to one another.

General relativity, however, is the difference in time perceived by two observers with different gravitational fields acting on them. When we calculate the difference in time perceived by the satellite as it is 19000 km above the earth, we find that it experiences time about 45,900 nanoseconds faster than us. So the difference between a clock on the ground and one on the satellite is 45900-7200 nanoseconds a day. That's 38700 nanoseconds a day, or about 0.0000387 seconds a day, 0.01414 seconds a year, or about one second every 70 years.

GPS requires a real time margin of error of no more than 30 nanoseconds to achieve accuracy to about 10 metres, and of course, because of relativity, without correction, this would be inaccurate by about 38000 nanoseconds a day! Add to that the fact that GPS needs data from at least 4 satellites to work, and you see the problem getting compounded pretty quickly. Estimates have shown that without accounting for relativity, GPS would start to get inaccurate in about 2 minutes, and in a mere day you would be about 10 kilometres off course, at which point the whole system is just useless. This was solved for by making the atomic clocks on board all GPS satellites tick 38,700 nanoseconds slower than the clocks on the ground before launch, so that when they were in orbit, they'd be in perfect sync with our clocks. Of course this is not completely perfect, and thus the computers on board the GPS satellites are capable of further error correction if and when their clocks go out of sync by more than a few nanoseconds.

However, as we've said before, classical gravity is still what's used by all space agencies, and without any problems. The future might need an all new theory of gravity that is compatible with quantum mechanics, and even general relativity might be replaced eventually with a grand unified theory that can find some relation between all of the four fundamental forces of nature. Add on to that the unknown – dark matter and the mysterious force of dark energy – and we might end up with all new theories that we can't even imagine right now!

Mechanics

Also known as classical mechanics, the study of mechanics is a very vast discipline. It is completely different from the area of study known as quantum mechanics, which we will come to later. Mechanics is essentially the study of physical objects and how they react when subjected to physical forces or fields. It deals mainly with objects that are at rest, or moving at low velocities as compared to the speed of light. It also only deals with objects that are orders of magnitude larger than atomic sizes.

For most everyday usage, classical mechanics is pretty much just Newtonian mechanics, which is unchanged since the 1600s when Sir

Isaac Newton first described it. Celestial mechanics, the study of the motion of celestial bodies such as planets, stars and even galaxies are also an example of classical mechanics.

Other sub-disciplines are solid mechanics, which look at the elasticity, plasticity and viscoelasticity of solids, and fluid mechanics which looks at the motion of fluids (liquids and gases). A sub-discipline that we all love is acoustics and sound transmission, which covers everything from the tonality of your headphones and speakers to the acoustics of a theatre, or even a large open field.

Biomechanics and biophysics look at the way in which joints, liquids and solids behave in biology, and this could include everything from how stuff is transported between cells in living things to advance biomechanics in sports that helps professional athletes improve, and of course medicinal mechanics such as implants, prosthetics and artificial organs.

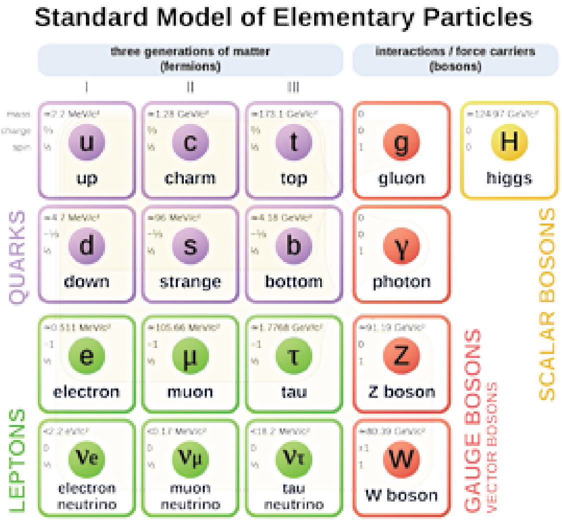
Hydraulics is a subsection of mechanics that makes use of the mechanical properties of liquids to use pressure to generate, control and transmit power across a mechanical system. Everything from the largest cranes used in mega-constructions to the shock absorbers in your bikes, or even the gel padding that you add to your shoes, it's all hydraulics. Similarly, pneumatics does exactly the same thing as hydraulics, but using gases instead of liquids.

The field of applied mechanics (also called Engineering Mechanics) kind of covers many sub-disciplines of mechanics, and puts them to use in engineering scenarios. This is essentially the mechanics that are taught and used in the fields of engineering such as mechanical, construction, civil, aerospace, electrical, structural, etc.

Quantum mechanics

Also known as quantum physics, this is the study of nature at the smallest scales of quantas of energy or atoms and their constituent particles. It's a newer branch of physics that was revealed to us once we were able to study properties at the atomic level. A brand new interpretation of the universe was born with the understanding of quantum mechanics, and it is being used with great success in multiple fields of study. The most important to us Digit readers is of course the field of electronics, which wouldn't exist without the understanding of quantum mechanics. Everything from lasers to transistors and semiconductors to superconductors all stems from quantum mechanics.

Even simple things like flash drives use the effects of quantum tunnelling to erase memory cells... Flash drives contain memory cells that have floating gate transistors – there is a control gate that's connected to a terminal, an insulation layer and then a floating gate inside the insulation that stores electrons. When a drive is wiped clean, all floating gates have the value 1 in binary. When electrons are trapped in the floating gate, the value is 0 in binary. In order to



Standard model of matter

erase the 0 and revert it to a 1, a strong positive charge is applied to the control gate, and then the electron tunnels through the insulation layer to the control gate, and resets the floating gate to the default position (1 in binary). Without quantum tunnelling, or at least without understanding how it works, we wouldn't have flash memory. Because the electron will not tunnel until the charge is applied to the control gate, flash memory stores information without the need for constant power to keep the information from being lost. For example, RAM requires consistent power to keep data from being corrupted, and losing power resets RAM to the default state, which is why RAM is called volatile memory, while flash storage is considered to be non-volatile memory.

Other areas where quantum mechanics is being used is in the field of quantum computing and also in cryptography. Quantum cryptography is considered to be the ultimate in secure communication, and although we cannot really achieve it right now practically, it will indeed make everything unhackable. This is because quantum cryptography relies on quantum entanglement to create a quantum key that is then distributed to the two people communicating. As we know, entanglement means that two quantum particles are entangled in a way that changing one of them will change the other instantly, no matter how far away in spacetime they are. Thus, if you have a quantum key distribution that is based on this effect, two people have a key that only they know and possess, and no third person can gain access to the key, even if they can gain access to the stream of communication. Because the key being used is based on entanglement, a third person trying to eavesdrop immediately changes the key, which in turn makes the communication total gibberish, not just for the eavesdropper, but also for the people communicating. This means that people will immediately know that there is someone trying to eavesdrop, and there is no danger of an eavesdropper listening for any period of time before they are discovered. In essence, a truly secure form of cryptography. Too bad it's still only in theoretical or prototype stages in research labs.

Quantum computing, on the other hand, is showing some promise, even if it is pretty useless without quantum cryptography just yet. Still, if one is ok relying on current levels of cryptography, the idea of quantum computers is interesting still.

The idea of quantum computers arose from a lecture that Richard Feynman gave in which he asked a simple question. Can we simulate quantum physics on a computer? And if we cannot, then can we build a computer that uses quantum principles to operate?

While a regular computer works with bits (1 or 0) a quantum computer works with qubits (quantum bits that can be 1 or 0, both 1 and 0, and also any of the superpositions of 1 and 0). Imagine a 3-bit regular computer. It could have any one value at a time – 000, 001, 010, 011, 100, 101, 110 or 111. A 3-qubit quantum computer, however, would be all of the eight states at the same time! Now, although this is a little hard to wrap one's head around, and it also seems kind of pointless at first glance... it is when you consider successive operations that it starts to make sense. Although oversimplified, imagine telling a 3 bit computer to calculate 7-4=?

This is something a regular computer can do instantly, right? Not quite, although it might take a few nanoseconds, the computer goes through the process of converting 7 to binary (111) and 4 to binary (100), and then running the subtraction operation to arrive at 3 (011). We're using 7 as a max here because in 3-bit binary it's the largest number that can be written down in one single operation.

Now, contrast this with the 3-qubit computer, which is already all of the eight numbers (from 0 to 7) at once. When you input 7, it just discards all the others, then you enter the subtraction operative, and it's already waiting with all ready answers for all the eight possibilities (7-0, 7-1, 7-2, 7-3, 7-4, 7-5, 7-6, 7-7). The instant you enter the 4, it displays the answer, as it merely has to discard the others, and doesn't execute the subtraction command after you enter the second number and press enter like a regular computer.

Remember, this is oversimplified to a level where it's probably incorrect in some way, but the idea here is to explain the concept rather than the actual workings of a quantum computer. Once you understand the concept, you start to understand how a working quantum computer that has the same amount of bits as a modern desktop computer would be more powerful than the most powerful supercomputer we've ever built. Getting it to work, however, is the problem, and getting it to work in an unpredictable end-user environment is the real challenge.

If we want to simulate a trillion atoms of hydrogen in space and see how they behave, a classical computer might be able to render that with some success, and pretty quickly as well. A quantum computer would do a much better job, and would do it far quicker. However, if you were looking to simulate the way the sun formed from a hydrogen cloud that was made up of 10^{57} atoms of hydrogen... you would certainly need a super-quantum computer to simulate that with real precision. With a classical computer, we are doomed to accept low fidelity approximations for such simulations.

Someone philosophically minded might suggest that a computer powerful enough to simulate the universe itself, might indeed have the computing power of a god...

Nuclear physics

This branch of physics studies the nucleus inside of atoms, what they're made up of, how they react, and more importantly, how to break them apart in order to release the energy they hold. As you would have guessed, nuclear physics mostly revolves around the field of nuclear reactors, and research in the field of nuclear material. Thus, whether it's nuclear power plants, or the building of nuclear weapons, or nuclear medicine, it all has to do with radioactivity in some way.

The field was born from the arms race and the production of nuclear weapons, and then went on to nuclear power generation as well. An offshoot is also the studies of carbon dating and other radioactive dating methodologies. It was the discovery of radioisotopes of certain elements that led us to understand that there could be a difference in two atoms of the same element, and one was stable while the other was radioactive. Every radioisotope has a different decay rate which can range from well under a second to trillions of years, and it is knowing and calculating these decay rates that allow us to assign date ranges to, say, fossils for example.

Nuclear fusion and fission are used mostly in weapon manufacture, but are also pursued for the purpose of energy generation. Nuclear energy production is considered to be one of the greenest energies, but of course, it requires significant costs to set up and run.

The most common use is of course nuclear medicine, which is when we use radioactivity to both diagnose and treat illness. Although we've all had X-rays done, that isn't a part of nuclear medicine, because it involves the use of a radioactive substance to record emissions from inside the body, unlike in x-rays where the EM radiation is passed through a body from an external source. PET scans (positron emission tomography) are the most common that some of us may come across during medical procedures.

In terms of treatments, some cancers can be treated with radiotherapy, which is not actually a part of nuclear medicine. A radiation dose given to you as part of a nuclear medicine treatment plan would be administered intravenously or by oral ingestion. They work because they have very low range ionising radiation, and thus are not a risk to other organs in the body, or indeed even other people. They're usually given to people with blood disorders, or thyroid cancer.

Optics

This is a very broad subset of physics, as it basically covers all properties of light, and explorers all the ways in which light interacts with the physical world. It also covers the whole spectrum of light, and not just visible light, so the range is from the low infrared spectrum through visible light up to the ultraviolet radiation.

The field is most easily broken up into classical optics and modern optics. Classical optics looks at light as either a wave or a ray (stream of particles travelling in a straight line). For certain applications, it's just a lot simpler to consider light to be rays that travel in straight lines. Also called geometrical optics, this field looks at light as simply rays that can be reflected or refracted. This is the level at which we learn about light in school, and it's what is used by optometrists everywhere.

Everything from the spectacles that some of us wear, to all of the mirrors, glazings for windows, and the like, is all based on classical optics. However, it's not all based on geometrical optics, as there is often a need to use physical optics when dealing with the properties of light. Physical optics is essentially a simplification of the precise science of electromagnetic theory, so as to be easier to do, and to be able to be used more broadly across multiple applications in daily life. Basically, what physical optics does is to treat light as a wave so that it can address properties of light such as interference, refraction and diffraction. This is because reflected and refracted light can do irritating things like reflections cancelling each other out when they're out of phase, or amplifying intensity when they're in phase, and refraction causing light to be split into component colours. If we didn't address this, and just assumed the geometric optics version of light, we'd have a lot of problems with unexpected behaviour.

Modern optics is the study of light, usually for research purposes, and interpreted using the modern electromagnetic theory of light. This includes, of course, the quantum theory of light, and takes into consideration the quantum behaviour of light and of the matter it is interacting with. Almost all research and development being done in the field of light engineering and electronic image sensing (yes, that's our digital cameras and smartphones) is done using the EM theory of light. It's not even all human vision based, as fibre optics and machine vision will attest to. And, it's not just light detection, but also light emission that's worked on – for monitors, screens of all types and projectors. Lasers are another example of modern optics at work, and we've now reached the sophistication of equipment and light generation to be able to emit and detect even single photons!

Particle physics

Yes, this is where things such as the LHC come in, and we encourage you to read our dmystify on that topic. It will cover particle physics far better than we can in this short space. In essence, particle physics is really high energy physics that attempts to smash particles together to see what they're made out of. It's a trillion dollar research industry that essentially panders to our basest impulses of wanting to smash stuff! Of course, there is loads of complex math that only a handful of people on earth are smart enough to understand, but in essence, we're pretty much like toddlers sitting on a floor and smashing two cars together to see what is inside. And boy did we see! After fears that the LHC might cause a mini black hole that will swallow up the earth subsided, the particle smashers got to work and out popped the higgs boson, just as some had predicted it would, and earned Peter Higgs a Nobel prize. Next on the to do list of huge particle smashers like the LHC is the attempt to discover what dark matter is, and whether it can be observed when we smash stuff at energies we can achieve over the next few decades.

Thermodynamics

This is a field of physics that studies heat, temperature, energy and work. Based in the four laws of thermodynamics, this field of study looks at everything from simple everyday objects to the entire universe as a whole, and everything in between as well.

The four laws are:

- Zeroth Law: If two systems are in thermodynamic equilibrium with a third system, they are also in equilibrium with one another. (If A=C and B=C, then A=B)
- First Law: The energy contained in a completely closed system is constant. It can never be created or destroyed, it merely changes forms.
- Second Law: Heat does not flow from a colder location to a hotter location. Entropy of a system reaches a maximum value at equilibrium.
- Third Law: As temperature approaches absolute zero, the entropy of the system approaches its minimum possible value.

Everything from climate change to weather predictions, and studying distant stars to the big bang, all has elements of thermodynamics in the research. On the largest scales it is the study of entropy, which is nothing but the amount of disorder and randomness in a system.

Inter-discipline

Apart from the broad fields we've mentioned thus far, there are also way too many interdisciplinary fields to cover in such a short space. However, we wanted to cover a few, just to give you an idea of the types of inter-disciplines that exist.

Biophysics

We've touched on biophysics under the header of Mechanics above. It requires knowledge of chemistry, molecular biology, general biology, systems biology, physiology, nanotechnology, and more. The 'physics' aspect of biophysics is limited to the study of purely physical parameters, such as temperature, pressure, electric current, physical measurements of size, elasticity, tensile strength, etc.

Chemical physics and physical chemistry

This is essentially the study of chemical processes from the point of view of physics, especially atomic and molecular physics. There is another branch called physical chemistry, which is the study of chemical systems using the theories of physics. The difference is that physical chemistry is usually more at a macro level, while chemical physics is mostly done at an atomic level. Chemical physicists study the structures of ions, polymers, molecules and free radicals using, amongst other theories, quantum theory. They want to know how chemical reactions actually take place... if we were able to watch every electron and atom interact with one another, what would that reaction actually look like in the physical world.

Physical chemists, on the other hand, are still physicists, but they look at chemical reactions in terms of motion, energy, quantum chemistry, mechanics and of course, thermodynamics. They want to answer questions such as: what forces act on materials, how is heat transferred from reacting elements to the chemical system the reaction is contained inside of, how electrochemical cells work, etc.

Computational Physics

Computational physics is essentially the study of how we can use computers to solve problems in physics, or to simulate experiments that we cannot perform using computers. It's often used to test theories and to check the math of physicists. Because of how broad the field is, it is usually lumped in with whatever research it is being used to conduct. If a computational physicist is working on simulations of a particle accelerator, he's just fulfilling the role of a particle physicist and just happens to be good at computer programming and languages.

Computational physicists are essentially building numerical models of their experiment that computers can then number crunch, and of course, it helps to be specialised in your field of research, and also in computer languages so that you can create your numerical models...

Geophysics

This is essentially a field that uses physics to study various phenomena that occur on the earth. Everything from analysing the earth's magnetic field, to the internal composition of the earth's core, and from plate tectonics to studying the water cycle... it's all geophysics. The fields of study such as gravimetry, seismology, geothermal studies, radiometric dating, fluid dynamics studies in oceanography, mineral physics, magnetosphere studies, and more... all form the field of geophysics.

Now, this list we've presented here are by no means exhaustive, and we dare say we've omitted more than we've covered, but that's only because there are a myriad specialisations that are possible in the world of physics. If you're still a student, we do hope that this chapter and even more so the next one will give you some inspiration in a field of specialisation. ■

Research and the future

What does the future hold for physics, and what are some of the problems it hopes to solve

While every field we have listed thus far will have their own set of specialised problems that hundreds of scientists are working to solve, there are a few huge problems in physics... no wait, let's rephrase that... there are still huge gaps in our knowledge of the physical world that are yearning for one of us to step in and solve. There are hundreds of Nobel prizes up for grabs, and all of them will be awarded over the coming decades. However, as of writing this book, there are some truly baffling mysteries that humanity as a whole would love to solve. Again, due to the lack of space, this is by no stretch of the imagination an exhaustive list, and if you would like to add a few research areas to this list, write in and tell us why you think we should have included it.

Theory of Everything

Although we have fairly well understood our physical surroundings, we have done so in silos. We know why light acts like a wave, we know why light acts as a particle, but we aren't exactly sure how light relates to gravity, for instance. We know gravity travels in waves as well, but how? What are the effects of gravity at the quantum scale? Is there a Grand Unified Theory (GUT) of the three fundamental gauge interactions – strong, weak and electromagnetic forces? Can this GUT be fitted into a Theory of Everything (ToE) with gravity? As of now, we have general relativity (GR) and quantum field theory (QFT), and neither play well with one another because GR looks at gravity and spacetime at the macro level of galaxies and stars, while QFT looks at the three other forces (and not gravity) and looks at the world as subatomic particles. QFT is the current forerunner for a grand unified theory, and thus, finding a way to fit it together with general relativity assures whoever achieves that a place in history that is right up there with Einstein and Newton. Currently, string theory is one of the most popular attempts at a ToE. Problem is, string theory, or M theory is very hard to test experimentally, and it raises more problems than it solves.

Dimensions

And here's where we run into the biggest problem of string theory and M theory. We are aware of four dimensions – three space and one time, which all band together to form Einstein's space-time continuum, but both string theory and M theory suggests that there are 10 or 11 dimensions (respectively). This means apart from the 4 we know of there are at least 6 or 7 more dimensions we have no clue about. Some versions of string theory have even raised that to 25 dimensions, but we're sticking with the most popular. You should read our dmystify of string theory to know more about it, and how it might be possible that there are more dimensions than we can perceive.

Time

If we're completely honest, we don't really know what time is. We can experience it, but we certainly don't know why it exists or what it is. Add to that, the fact that time seems to be constantly flowing in one direction, with no way to go backwards, we get what is called the arrow of time. This idea was thought up by the famous astronomer Arthur Eddington in 1927. He stated that time was asymmetrical, because if it was symmetrical, a video could be played backwards and forwards and no one would be able to tell the difference. Now, sure, you could take a video of something totally still and unmoving, like a wall, and play that forwards or backwards without knowing the difference, but what Eddington meant was that we always see plates falling and shattering, but we never see smashed pieces of the plate form together and fly upwards from the ground back onto the table.

Because entropy of a system only ever increases, it is thought that time and entropy are closely related. Are there other universes where time runs in the opposite direction to us? Would the sight of a plate falling off a table and smashing startle a resident of that universe just as much as the sight of a plate magically reforming itself would startle us? These are questions just waiting to be answered, and for now it's the philosophers who are talking more about it than the physicists.

Dark matter and energy

If you had only studied 4% of your textbook and syllabus before sitting for an exam, you would feel pretty ignorant indeed. That's how physicists feel today, knowing that we only know of and interact with a miniscule percentage of substances in the universe. In case you haven't bought the digit package for the month in which we did some of the dmystifys mentioned in this book, just drop an email to *archive@digit.in* and you will receive an automated reply that gives you access to all our older content for free. So make sure you do that.

Size of the universe

Because the speed of light has a limit, and can only travel at just under 300,000,000 m/s in vacuum, and because it's only been 13.8 billion years since the Big Bang, we can only see a sphere of a diameter of 93 billion light years. This is what we call the observable universe, and it stretches out for 46.5 billion light years on every side. Why 46.5 and why not 13 billion light years on every side? That's because spacetime is also expanding, and thus the universe is stretching outwards. Only objects that are 46.5 billion light years away from us now emitted light that has had enough time to reach us. As time passes, we will get light from objects that are even further away, but even that has a limit. At a point 62 billion light years away from us, spacetime itself is moving away from us faster than light, and thus, light from anything in that region and beyond just cannot reach us. Ever! Between the 46.5 billion light years we can see now, and the max of 62 billion we can ever hope to see lie some galaxies waiting to be revealed. Whether we will be around to see them when they become visible is doubtful though.

Black holes

Theoretically and mathematically we know what black holes are. However, ideally we'd love to study these mammoth holes in space time. Sadly, we're not going to be able to do so anytime soon, unless we create our own. Not just ordinary black holes get our attention, but also supermassive ones, which we think are at the centre of every galaxy. There is so much more to learn about them, and there are plenty of awards that are waiting to be won in the field. If and when we do confirm the existence of Hawking radiation being emitted from a Black Hole, and prove professor Hawking right, he still will never be awarded the Nobel prize, because it isn't handed out posthumously. :-(

Wormholes

Although more science fiction than science, wormholes catch our fancy for a reason – they make faster than light travel possible. The explorers in all of us are itching to go to another planet, or even better visit another civilisation in a different galaxy, perhaps. Also called Einstein-Rosen bridges, wormholes have never been observed, so we don't even know if they exist in nature.

Space Roar

We suggest you read our article on this topic inside Digit April 2019. Since this book has come bundled with that same issue, we find it pointless to repeat ourselves.

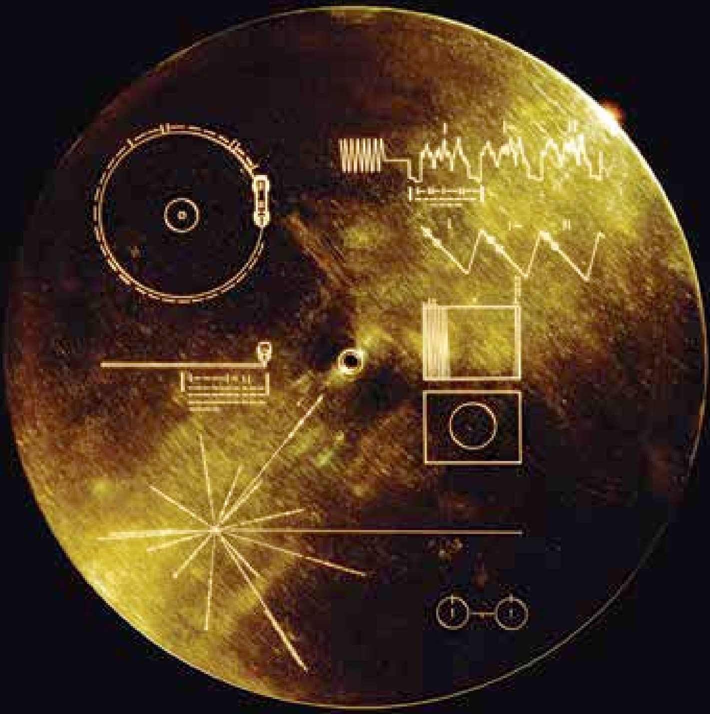
Axis of Evil

The cosmic microwave background radiation is essentially a baby picture of our universe. For the most part, it is a flat and faceless image of just microwave noise. However, it has tiny anomalies in about one out of 10,000 parts, and these anomalies are essentially slightly hotter or colder regions. Scientists began mapping the anomalies in order to study them, and when they threw it all together in a spherical map, they found that the CMB is colder above the solar system's axis and hotter below.

The measurements are done in increasing amounts of poles. So a monopole result is the whole spherical image of the CMB. A dipole looks at northern and southern hemispheres. Then it's done with 4, 8, 16, 32... and all the way up to about 4000-poles. The reason it's done is to equate the differences between ever decreasing slices of the sky – in an attempt to find more accurate temperature differences in the CMB. Turns out, the 4-slice and 8-slice matched almost perfectly together, and it showed that the solar system almost precisely cuts the CMB into a hotter and colder region, which is odd because the CMB was released billions of years before the galaxy even formed, let alone the formation of the solar system.

Because it was at a time when George W. Bush was calling three countries (Iran, Iraq and North Korea) the "axis of Evil" the scientists used the same name to describe the problem they had. Many believe that it is a mere coincidence, or perhaps a case of apophenia. While others go to the other extreme and assert a divine plan. We will need to study it more closely before we can come to any conclusions, but for now, it's a very problematic anomaly.

We hope you like this book and that it whets your appetite and causes you to read up more on the topic. As always, remember to send us feedback at *dmystify@digit.in*. ■



Cover of the Voyager Golden Record

https://dgit.in/dmy0419

Credit: NASA/JPL