A Project Report on

An Introduction to Quantum Computers

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CERTIFICATE

This is to certify that the project work entitled "**An Introduction to Quantum Computers**" is a bonafide work carried out by **Jyothi N (160115733126), Komal P (160115733127), Krishna Sri S (160115733128), Lehya Reddy K (160115733129),** and **Madhuri V (160115733130)** in their fifth semester as part of the course work of Soft Skills and Employability Enhancement under our guidance and supervision. The results embodied in this report have not been submitted to any other university or institute for the award of any degree or diploma.

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ACKNOWLEDGEMENTS

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We would like to thank Smt G. Mercy Rani for her patience and for guiding us despite her academic and professional commitments. We are grateful to the Humanities Department for giving us the opportunity to do this project.

We would like to express our gratitude towards the members of Indian Institute of Chemical Technology for their kind cooperation, attention and time, especially Dr K. Venkatram Reddy, Public Relations Officer and Dr K. R. Ganesh who have been extremely hospitable during our visit there.

We would also like to thank our families for their constant support and encouragement.

PROJECT DESCRIPTION

Organization visited

CSIR-Indian Institute of Chemical Technology (IICT), Tarnaka, Hyderabad

Objective

The main goal of this project is to understand the working and
functioning of an organization. Industrial visits are so important in the career of a student pursuing a professional degree that they are even considered as a part of the college curriculum. They give an insight into the internal working of companies and organizations. Theoretical knowledge is not enough for making a career; activities like industrial visits

provide us with a practical perspective on the professional world -- something that employers are looking for.

Apart from this, we also wanted to learn how advancements in the field of Chemistry are being applied to the field of Computer Science.

INTRODUCTION

Indian Institute of Chemical Technology (IICT), Hyderabad, established in 1944, is a constituent laboratory of Council of Scientific and Industrial Research (CSIR), New Delhi. With its expertise in chemistry and chemical technology, it provides solutions to challenges faced by Industry, Government Departments and Entrepreneurs through basic and applied research, and process development. It is internationally recognized for its contributions to chemistry research and is an ideal place for taking ideas to commercialization through state of the art research and development.

CSIR in its bid to ensure better recognition and visibility, had decided to add the suffix 'CSIR' to all labs during 2010-11. Subsequently, IICT is now referred as CSIR-IICT.

Vision

- To become the first line of support for innovation by Indian chemical and pharmaceutical industries in their endeavour to become globally competitive.
- To provide scientific and technical assistance for Government of India campaigns like Swachch Bharat, Swasthya Bharat, Samarth Bharat and Make in India, with its expertise in chemistry and chemical technology.
- To help Government ministries, NGO organizations, entrepreneurs and industry, in projects of social responsibility, and those that create wealth and employment for the nation.
- To partner with Indian strategic organizations in their quest for new materials and specialty chemicals critical for progress of our nation.

Mission

- To achieve excellence in chemistry, chemical technology and allied fields through Research and Development on topics which are current and relevant to India.
- To identify, pursue, create and make available chemical technologies that are capable of making India a major contributor to knowledge economy.
- To practice high science of international standards by networking and collaborating with Universities, Laboratories and industries of high repute across the world.
- To nurture talent, competency and scientific temper of staff in all allied fields of chemistry and chemical technology such as organic synthesis, catalysis, chemical engineering, materials, and analytical science.
- To leverage IICT's human resources and facilities to produce tangible outputs like products, processes, patents, and publications to contribute towards creation of wealth for the country.
- To provide training for Ph D students in interdisciplinary and current research topics to fulfil the scientific manpower requirements of Industry and academia.

METHODOLOGY

We had a **discussion** with Dr K. R. Ganesh, an interdisciplinary sciences enthusiast who introduced us to the power of Quantum Computers. We were a few questions to gauge how much we knew about the concept already and talked about the notions that we could learn more about. Some of these questions are:

1. Have you ever heard about quantum computers? What do you know about them?
2. Have you heard about the God particle?
3. Do you know about quantum entanglement and quantum tunneling?
4. What is dark energy and dark matter? How much of the universe is estimated to have been made up of them?
5. What are protons and neutrons made up of?

We were able to answer most of these questions and when we could not, he explained the concepts clearly and also added how they are related to quantum computing. He entertained many questions from our side too some of which include:

1. How can advancements in chemistry be applied to the field of Computer Science?
2. Why do we need quantum computers? If research is continued, can't we improve the capabilities of classical computers?
3. Will quantum computers replace classical computers in the future?
4. What kind of problems will quantum computers be able to solve?
5. How much progress has the world achieved in this field?

The following section contains the answers to all of the above questions and more. We have also included any related information from various books and the Internet.

ANALYSIS

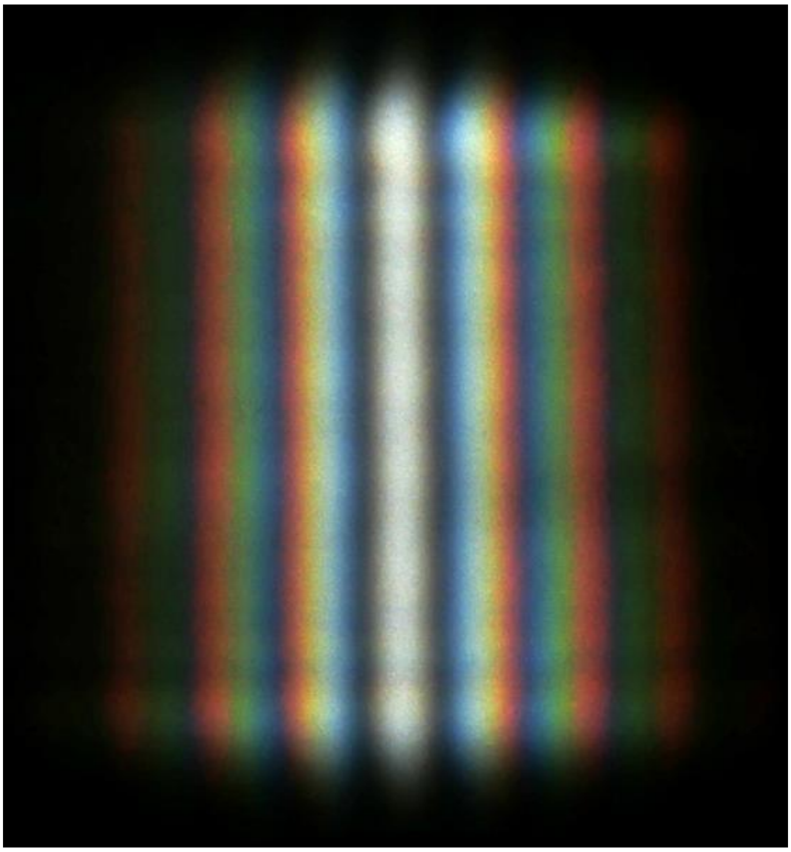
Introduction

To understand how scientists are trying to implement quantum computers, we first require a knowledge of certain theories of quantum mechanics. Quantum mechanics is the fundamental theory of nature at the small scales and energy levels of atoms and subatomic particles. Particles at this scale behave in a bizarre manner. This is not observed in particles at the macroscopic level because of their very small wavelengths when compared to the size of the actual object.

The Double Slit Experiment

The double slit experiment will give an idea of how quantum mechanics is weird. If you are shooting small objects, like marbles through a slit, onto a screen, then you start observing a pattern on the screen after a while. This will be similar to the slit that you are shooting the marbles through. Even if we have waves passing through the slit instead, we observe a similar pattern. However, if we have two slits instead of one, then the marbles and the waves behave in a different manner. The marbles will simply cause another pattern similar to the second slit introduced. But the waves form something called an interference pattern which is formed because the trough from one wave and the peak from the other wave cancel out each other, whereas the peaks from the two waves increase in intensity.

Now if perform the same experiment at microscopic level, sending electrons instead of marbles through a slit of comparable size, we observe the same pattern as with the marbles. But it gets interesting when we introduce another slit. Electrons form an interference pattern as opposed to a two-band pattern. Physicists proposed that the electron becomes a wave before entering the slit, interferes with itself, and then goes back to being a particle. So mathematically speaking, the electron goes through the first slit, the second slit and through both the slits at the same time. This is what being in a state of **superposition** means. Then physicists attempted to prove this by observing the electron before it enters the slit. Bizarrely, the electron remained as a particle and created a two-band pattern! That is, the simple act of



Double-slit interference of the sunlight

observing somehow collapsed the wave function and caused the electron to revert back to particle behavior. Now the scientists decided to switch on their detectors after letting some of the electrons pass through the slit. However, the electrons created a two-band pattern even though part of them were not observed. The physicists started calling them **time traveling electrons**. In reality, they were not really time traveling. As soon as the detectors were switched on, they erased any evidence of superposition and reverted back to their particular nature.

Of all the theories attempting to explain this phenomenon, the **Many Worlds Theory** garnered maximum attention. It states that anything that can happen does happen and that when a system is observed, it collapses into all of the states but different worlds will observe different results. So instead of just one world, there are many different worlds. Every time there is one or more options available for the universe, the universe splits and creates copies where all possible outcomes come true. So, for example, there could be a world where Hitler won the World War II.

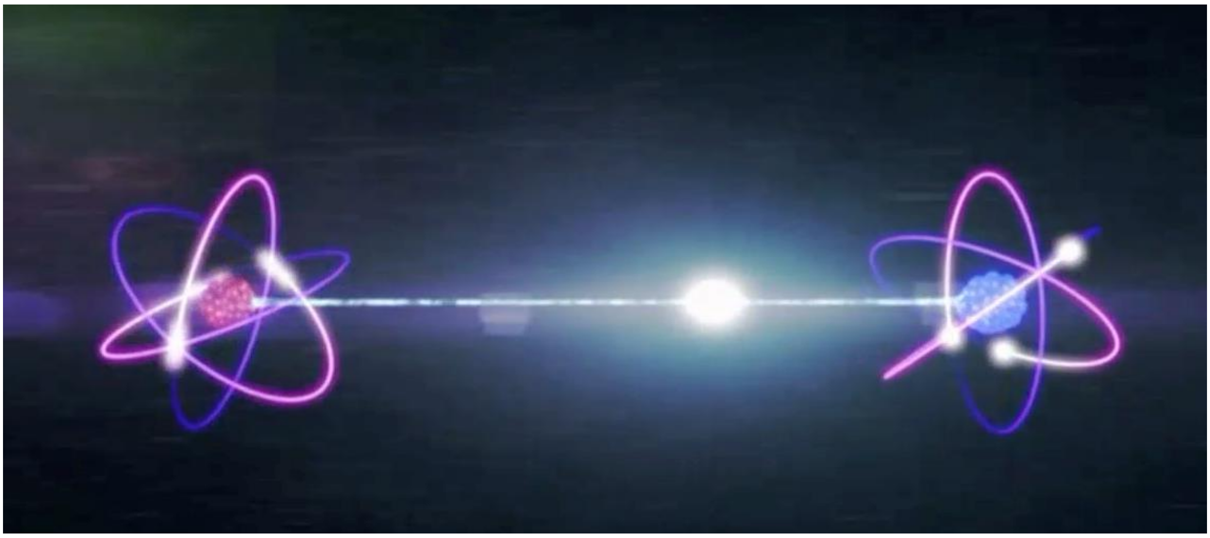
The Superposition Principle

This principle proposes that a system will exist in all possible states that it can have until it is measured or observed. Then the system will have to choose which of its many states it should be in.

Schrodinger's Cat

Schrodinger’s cat is a really famous thought experiment that tries to explain this principle. A cat is placed in a closed cardboard box with a radioactive sample that has a 50% chance of decaying and killing the cat. The cat can be in two states, either dead or alive. When the box is covered, we have no way of knowing in which state the cat is in. If we apply the superposition principle, then the cat could have been dead and alive at the same time, given that the box was covered and the cat was not being observed. Only when we open the box did the superposition collapse to reveal whether the cat is dead or alive.

Quantum Entanglement

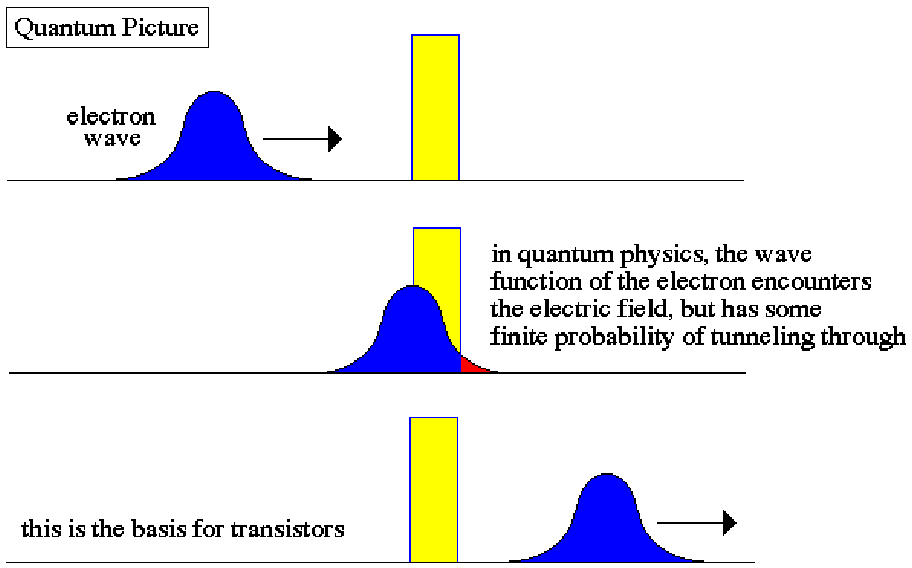


Quantum Entanglement

Quantum entanglement occurs when two particles become connected in such a way that when the property of one particle is changed, an instantaneous change in the property of the other particle occurs. Entangled particles have the opposite properties or states. Particles have a property called spin and they will either be a spin-up or a spin-down in any given direction. So, when two particles are entangled and their spins are measured in the same direction, one particle will be spin-up and the other particle will be spin-down. According to quantum mechanics, a pair of entangled particles could be separated by an entire universe and when the state of one is measured and its superposition is collapsed, it would immediately collapse the superposition of the other particle. Measurement would indicate that it had the opposite state of its entangled partner. That is, entangled particles can communicate with a speed faster than the speed of light. Something that Einstein's Theory of Special Relativity ruled out. Einstein called this **Spooky Action at a Distance**.

Using quantum entanglement, scientists have been able to **teleport** particles. Two particles, A and B, are entangled and separated by a large distance. A third particle, T is brought in and this is the particle that we want to teleport. This particle T interacts with particle A and the information of how particle T relates to particle A is sent across to where the particle B is kept. As the particles A and B are entangled, this information about how the quantum state of particle T relates to particle A will also reveal how the quantum state of particle T relates to particle B. Particle B will then be manipulated to replicate the quantum state of particle T, becoming an exact copy of the particle T. Meanwhile, the original particle T is destroyed as its information has been extracted and sent across. This method of teleportation has only ever been done on particles. A single human being contains a huge number of particles and that would mean an immense amount of data will need to be transferred for human teleportation. Using the means we have today, this would take upwards of quadrillion years. Also, there is the philosophical debate of whether the teleported particle T is actually the original particle T or just a precise copy of the original particle.

Quantum Tunneling



Quantum Tunneling

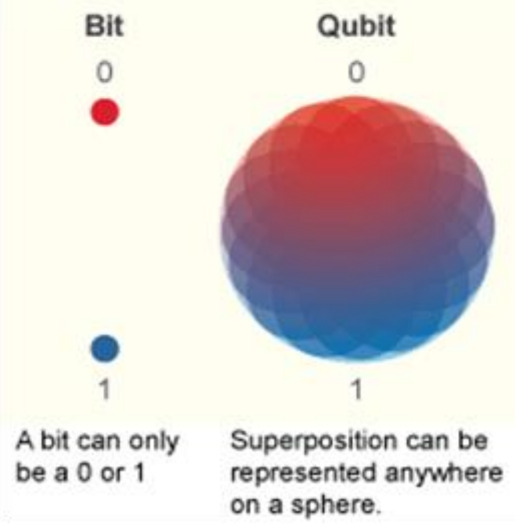
If we oversimplify the concept, imagine you are throwing a ball at a glass window and it bounces back to you. You keep doing this. But then, at a point, your ball did not bounce back to you and just went through the window, without smashing the glass. This is quantum tunneling and this phenomenon is how the Sun can generate energy through nuclear fusions. When two hydrogen atoms come together, the protons in their nucleus bounce off each other. If it was not for quantum tunneling, the protons would simply bounce off each other and nothing would happen. What actually happens is they quantum tunnel into each other and that is what lets them fuse and release the sunlight.

Quantum Computers

Since the 1960's, the power of our machines has been growing exponentially, allowing computers to get smaller and more powerful at the same time. But this process is about to meet its physical limits. Computer parts are approaching the size of an atom. An idea of quantum mechanics will help in understanding why this is a problem.

A computer is made up of very simple components doing very simple things. Computer chips contain modules, which contain logic gates, which contain transistors. A transistor is a simple form of data processor in computers, basically a switch that can either block, or open the way for information coming through. This information is made up of bits which can be set to either 0 or 1. Combinations of several bits are used to represent more complex information. Transistors are combined to create logic gates which still perform very simple operations. Combinations of logic gates finally form meaningful modules, say, for adding two numbers. Once you can add, you can also multiply and once you can multiply, you can basically do anything. Since all basic operations are literally simpler than first grade math, a computer can be imagined as a group of 7-year-olds answering basic math questions. A large enough bunch of them could even compute complex astrophysics problems.

However, with parts getting tinier and tinier, quantum physics are making things tricky. In a nutshell, a transistor is just an electric switch. Electricity is just electrons moving from one place to another. So, a switch is a passage that can block electrons from moving in one direction. Today, a typical scale for transistor is 14nm, which is about 500 times smaller than a red blood cell. As transistors are shrinking to the size of only a few atoms, electrons may just transfer themselves to the other side of a blocked passage via quantum tunneling. In the quantum realm, physics works quite differently from the predictable ways we are used to and traditional computers just stop making sense. We are approaching a real physical barrier for our technological progress.



Bits v/s Qubits

To solve this problem, scientists are trying to use these unusual quantum properties to their advantage by building quantum computers. In normal computers, bits are the smallest unit of information. Quantum computers use qubits which can also be set to one of two values. A qubit can be any two-level quantum system, such as a spin and a magnetic field, or a single photon. 0 and 1 are this system's possible states, like the photon's horizontal or vertical polarization. In the quantum world, the qubit does not have to be in just one of those, it can be in any proportions of both states at once. That is, it can be in a state of superposition. But as soon as you test its value, say, by sending the photon through a filter, it has to decide to be either vertically or horizontally polarized, as the Superposition Principle states. So as long as it is unobserved, the qubit is in a superposition of probabilities for 0 and 1, and you cannot predict which it will be. But the instant you measure it, it collapses into one of the definite states.

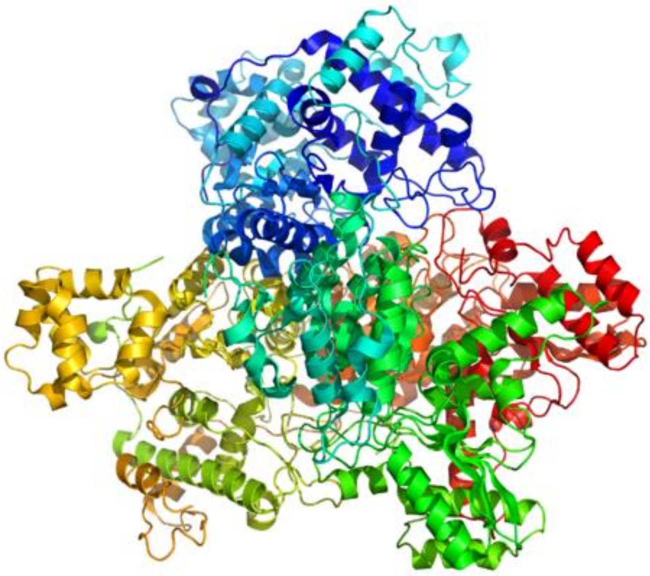
Superposition is a game changer. Four classical bits can be in one of two to the power of four different configurations at a time. That is sixteen possible combinations, out of which you can use just one. Four qubits in superposition, however, can be in all of those 16 combinations at once. This number grows exponentially with each extra qubit. Twenty of them can already store a million values in parallel. This is termed as quantum speed-up.

A really weird and unintuitive property qubits can have is entanglement, a close connection that makes each of the qubits react to a change in the other's state instantaneously, no matter how far they are apart. This means when measuring just one entangled qubit, you can directly deduce properties of its partners without having to look. Qubit manipulation is a mind bender as well. A normal logic gate gets a simple set of inputs and produces one definite output. A quantum gate manipulates an input of superpositions, rotates probabilities, and produces another superposition as its output. So, a quantum computer sets up some qubits, applies quantum gates to entangle them and manipulate probabilities, and then finally measures the outcome, collapsing superpositions to an actual sequence of 0s and 1s. What this means is that you get the entire lot of calculations that are possible with your setup, all done at the same time.

A typical Data Center

Ultimately, you can only measure one of the results and it will only probably be the one you want, so you may have to double check and try again. But by cleverly exploiting superposition and entanglement, this can be exponentially more efficient than would ever be possible on a normal computer. So, while quantum computers will probably not replace our home computers, in some areas, they are vastly superior. One of them is database searching. To find something in a database, a normal computer may have to test every single one of its entries. Quantum algorithms need only the square root of that time, which for large databases, is a huge difference.

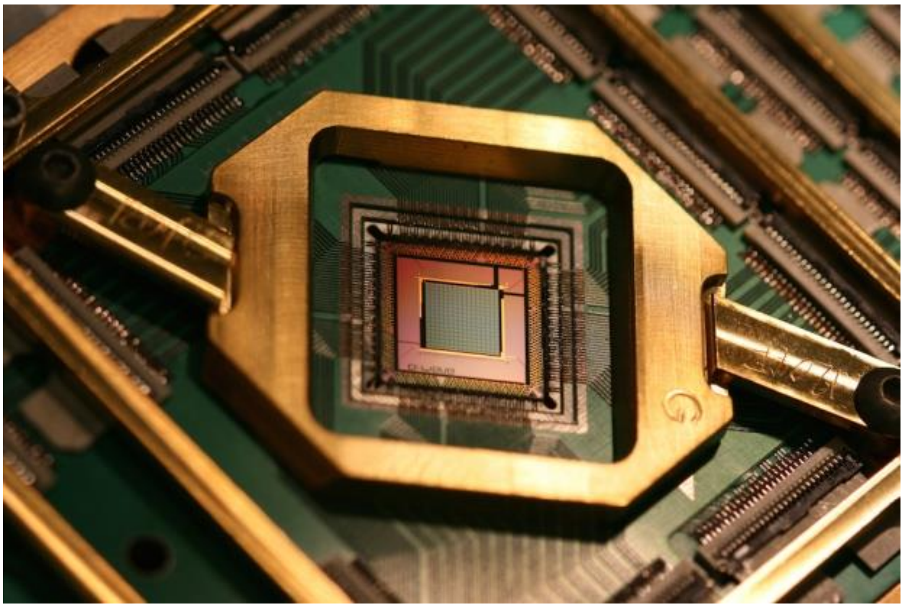
The most famous use of quantum computers is ruining IT security. Right now, your browsing, email, and banking data is being kept secure by an encryption system in which you give everyone a public key to encode messages only you can decode. The problem is that this public key can actually be used to calculate your secret private key. Luckily, doing the necessary math on any normal computer would literally take years of trial and error. But a quantum computer with exponential speed-up could do it in a breeze.



The complexity of a protein

Another really exciting new use is simulations. Simulations of the quantum world are very intense on resources, and even for bigger structures, such as molecules, they often lack accuracy. So why not simulate quantum physics with actual quantum physics? Quantum simulations could provide new insights on proteins that might revolutionize medicine. Right now, we don't know if quantum computers will be just a very specialized tool or a big revolution for humanity.

According to Microsoft's research lab, we could crack the quantum computing code within the next 10 years. Both Google and Microsoft are extremely invested in the idea of quantum computers, because they have a whole lot of data that they would like to tackle. So they have got some of the world's best quantum scientists trying to figure out how we can clear the final



Quantum Computing Processing Unit from D-Wave

hurdles. In Australia, engineers at the University of New South Wales (UNSW) have just figured out how to build a quantum logic gate out of silicon for the first time -- a major step forward in the development of the technology. Interestingly, a Canadian firm called D-Wave claims that it has already sold quantum computers to a number of labs around the world including Google's Quantum AI lab. But researchers say these machines haven't actually demonstrated the quantum speed-up effect yet, to which D-Wave disagrees.

REFERENCES

A Textbook of Engineering Physics – M N Avadhanulu and P G Kshirsagar

https://en.wikipedia.org/wiki/Quantum_computing

https://tinyurl.com/y9oe33qw

https://tinyurl.com/y8za5weo

https://tinyurl.com/y7pvoe82

https://youtu.be/7u_UQG1La1o

https://youtu.be/ARWBdfWpDyc

https://youtu.be/JP9KP-fwFhk

https://youtu.be/JhHMJCUmq28

https://youtu.be/w_-_H9eBte8

CONCLUSION

This industrial visit has been a real learning experience for all of us. Although we did cover most of these concepts of Quantum Mechanics in our academic curriculum, we never really grasped the ideas properly. We were not aware of the huge role that quantum computers would play, once they become a reality.

The visit also made us realize how the borders between various fields are thinning. We were not expecting to learn something related to our stream when we first stepped into IICT. We are very much grateful for having this opportunity to learn through an industrial visit.