

Good afternoon faculty, staff, important guests, students and family.

I want to talk with you about water and how it relates to your graduation here today. Water is the main component of beer as you know. I hope you understand the significance of what I just said. If not, let's make it clear. You have graduated from university. It is one of the most important accomplishments any individual in any country on the planet will accomplish in their lives. You should feel proud and you should celebrate. That is where the beer enters! In Canada we always celebrate with beer. Congratulations! By the way, India is well known around the world for excellent beer.... and high quality tea. Of course tea is composed mostly of water as well, but I do not think of it as a celebratory liquid....however, if you do, please let me know and we can substitute your beer with a cup of tea.

This convocation address will at least be unique. I could find no convocation address anywhere in the world that focused on water. I am surprised, aren't you? Today we are celebrating your completion of your studies. But my message today is not about completion but about starting. I want you to start being a curious person for the rest of your life. The key to eternal happiness is curiosity. Be curious about everything. I am curious about where water comes from. What are you curious about? I believe that mental health is maintained by the excitement from asking a question and pursuing the answer. Importantly, this curiosity doesn't have to be limited to your day job. Certainly, as a scientist, or an engineer, or as an economist, or a historian, being curious will drive you to excel. The right question at the right time can have a huge impact on a meeting, on a person, on your partner, on your boss! Being curious means your brain is working. It is like exercise. We all know exercise is good for your body, and it is not clear that mental exercise is good for your brain's health, but I am willing to say that it is. It is being refueled, refreshed, and strengthened. By the way, the brain is 78% water, 12% lipids, 8% protein and 1% carbohydrates. By my calculation, that beer should be good for your brain. My point is very simple. If you are curious about your job, about your country, about the people around you, about why things are the way there are, then you are in good shape. Educated people such as yourselves, will gain much happiness from learning, especially if you asked the question yourself and then discovered the answer by yourself. Sometimes you simply "Google" the question, and get a 1000 answers, or maybe you build the Large Hadron Collider, and 20 years later you and several other thousand physicists discover the Higgs Boson. It is up to you.

Now I am a particle physicist. I think about the world in a way that I have been trained to think. I am a reductionist. First what is water and where does it come from? My first question about water is where does the hydrogen and oxygen come from. A physicist knows where they come

from. Hydrogen formed about 400,000 years after the Big Bang. That is the temperature at which electrons can bind to protons to form hydrogen. The photons that are everywhere in that initial “expanding ball of space and matter” are now free streaming and the science from studying the so called 3 degree cosmic radiation is what led to the modern field of cosmology and the exciting science of dark matter, and dark energy. But let’s stay focused on the hydrogen and oxygen. Oxygen does not form in that primordial expansion, the protons and neutrons are too far apart to stick together. Hydrogen, helium, and some lithium is formed but that is it. Now somewhere up to 300M-400M years the first stars form. They cannot be observed directly with today’s powerful telescopes, at least not yet. Astronomers are very curious people and are building massive telescopes that will be sent into outerspace to observe light from those first stars. It will require the force of gravity to form the first stars and from detailed simulations we think they may have been a 30-50 solar masses. They are absolutely huge suns. There were no heavy elements at that time and the hydrogen was hard to cool and thus contract. When hydrogen collides with hydrogen, the excited states emit photons and cool the gas. Heavier atoms have more energy levels and electrons and so can emit a much broader range of photons and cool quicker. You have all heard of dark matter. It is thought it was created in the big bang. Curious people at CERN, in underground laboratories around the world, including Canada’s SNOLAB, are searching for dark matter. The role of dark matter is important probably in forming the initial stars, bringing of matter together, but after that the dark matter mostly interacts with itself through gravity. The ordinary matter interacts and cools by scattering off of other ordinary matter. What happens next is also a little unclear but the hydrogen burns into helium and three helium atoms combine to make a carbon atom, four would make oxygen, and so on up to iron, where solar burning stops. These first stars are thought to have lived for about 100,000 years...not long at all. The first stars end their life in massive explosion called a supernova. Nothing was left. No white dwarf, no neutron star, no black hole. All matter was expelled into space but it was no longer just hydrogen and helium but contained carbon and oxygen made in the solar furnances. Our sun is already 5B years old, and so 100,000 years is not long at all. The carbon and oxygen from those early solar furnaces gets expelled in space and then gravity attracts the cloud back together again and the process repeats, but this time these heavier elements make a more compact star and the subsequent death of that star may be a supernova explosion with a neutron star or even black hole as a remnant. The supernova explosion then is thought to make the remaining heavy chemical elements but that is not actually understood.

Let me share a small side story with you for a minute. India is the largest consumer of gold of any country on the planet, mostly for jewelry. Where is gold made in the universe? Have you ever been curious where the gold atom is made in the universe? The answer is the r-process or rapid neutron capture process. Half of all elements heavier than iron are thought to be made in the r-process. This is a mechanism during the supernova explosion where neutrons are quickly

added to core nuclei during the explosion making the heavier elements. The detailed nuclear physics explains why certain unstable, key word is unstable, nuclei decay and eventually make stable elements such as gold. The VECC laboratory in Kolkata, formerly headed by Professor Sinha, will use unstable nuclei to study the r-process using ultra-modern accelerators. In fact much of the world of nuclear physics is trying to better understand the r-process and where gold, for example, is made. Some astrophysicists think gold is made in the collision of neutron stars, which are the remnants of supernova explosions. So the next time you buy your mother some nice gold jewelry to thank her for raising you and encouraging you to go to university and....well here you are today....mention to her the gold may have come from a supernova explosion shortly before our solar system formed about 4.5B years ago, or maybe merging neutron stars! No, your mothers' did not pay me to say that. It is important to thank your mother and father and family for getting you here today.

Ok back to where water comes from. This subject is one of active research in a number of fields but let's just touch on the connection between India and Canada. Let's talk briefly about a connection between India and Canada, or more precisely, British Columbia, the province that contains Vancouver....the home of TRIUMF, Canada's particle and nuclear physics laboratory. Canada was a British colony just like India. Not surprisingly, Canadians drink tea. My theory is this started at the so called Boston tea party, when the Americans threw tea into the Boston harbor to protest high taxes from Britain. At that point, tea drinkers (called royalists) moved north, started Canada, and drink tea to this day. Furthermore, as I said, Americans today still hate to pay taxes, but Canadians like to pay taxes, another reason to move to Canada! I am not sure whether Indians like to pay taxes.... so much for cultural links. In 1911, a meteorite fell in Rajsathan India. It is one of five CI (CI (Ivuna type) chondrites found in the world. It has a name, the Tonk meteorite. Its mass is 7.7g and is one of only 5 of this type found anywhere on our planet.... just five little rocks.... one of which is from India. These rocks have a chemical composition that closely resembles that of the sun's photosphere and therefore was made early in the creation of the solar system. Interestingly, one of the other five chondrites was found in Revelstoke British Columbia, from a meteor shower observed March 31, 1965. Four pieces of mass of 1g was found. Yes, 1 gram....and they were found by beaver trappers. The beaver is Canada's Bengal Tiger, it is the national animal. It lives in the water. How exciting is that! So Canada and India have much in common. We like tea. We have common carbonaceous chondrites CI1 meteorites, and we like to pay taxes.

Water is also necessary for plate tectonics. India was formed by the India plate breaking away from Madagascar and drifting over and colliding with the Eurasian plate and forming the

greatest mountain range on earth and the Indian Ocean. The late Professor Wilson from the University of Toronto was one of the fathers of plate tectonics. He is credited with developing the idea that at various times in the past the continents have combined and separated and then combined again. The mechanism for this process is known as the Wilson Cycle. An important part of plate tectonics is plate subduction. Subduction relies on the water molecule that weakens the near-surface rock. The planet Venus has no plate tectonics, nor our moon, and lack of water is hypothesized as one of the reasons.

Ok, back to where water comes from. Some say comets. Not likely the only source. Some say the earth's mantle. More recent evidence is looking at meteorites. The CI1 type mentioned earlier have the right isotopic ratios to be consistent with our ocean water. The ratio of deuterium to hydrogen(D/H ratio) of the comets is approximately double that of oceanic water. Some scientists think most of today's water comes from the meteorites formed in the outer asteroid belt as indicated by the D/H proportions in carbon-rich chondrites. As I said earlier, the water in carbon-rich chondrites has a similar D/H ratio as ocean water. So the answer is not yet firm.

In summary, you have learned that nuclear astrophysics and laboratories like the VECC in Kolkata, CERN, and TRIUMF are solving the mysteries of where the chemical elements in the universe were created. The scientists pursue the big questions because they are curious. I am asking you to always be curious. Pursue your own questions. My question is..... where does water come from? What is yours? As the great Bengali poet laureate Tagore said, "Reach high, for stars lie hidden in you. Dream deep, for every dream precedes the goal."

....and on this very special day for you, don't forget three things:

- 1) Thank your family, they got you here.
- 2) Thank your teachers....they have helped form you as a thinking curious person who will hopefully contribute to making India and the planet a better place.
- 3) Thank yourself, you have accomplished something significant.....and enjoy that Kingfisher!