What do we look for in crystals? What makes them valuable? Is it how shiny they are or how “pretty” they look? Is it the number they read on the scales or how much they fetch you at the local cash converters? These are all things that would be valued, if you were reading a “Precious Rocks Collection” Magazine. However strange it may sound, the answer is in fact impurities. That’s right: Impurities. Physicists such as Dr Daniel Creedon of the Frequency and Quantum Metrology Research Group (FQM) at UWA’s School of Physics have been studying and experimenting on the effects of impurities within crystals with the aim of leading to a colossal breakthrough in Quantum computing, a form of computer technology that will change everything we know forever.

Want to multiply two 64 digit prime numbers together? Sure, just plug it into a computer. Want to find out what two 64 digit prime numbers multiply to give you the number you already have? Sorry, completely different ball game. Working backwards in complex problems is just one simple benefit quantum computers have over conventional computers.

Ever since Konrad Zuse designed the first mechanical computer, the Z1 in 1938 in Berlin, computer technology has only been able to process and encode information in binary. However, Quantum computing will change this by having the ability to exploit the laws of quantum physics and use its theory and mechanics to process information.

Keeping this as simple as possible, quantum physics has a very strong principle called “Superposition” whereby something like an electron can be both “up” and “down” or “here” and “there” at the same time. Now these quantum effects can be applied to future computing and communications technology. In short, modern conventional computers can only process information as zeroes and ones, but quantum computers will be able to process information as ones, zeroes and “Superpositions” of ones and zeroes.

As a result, this will open doors to limitless possibilities. Being able to develop safer and more efficient transport. Being able to solve complex algorithms and break seemingly impenetrable codes. Being able to map amino acids to create new drugs and fight diseases. The age of quantum computing is a closed pearl just waiting to be opened.

However, how will we open it? This is where the impurities come in (pun unintended).

Within an aluminium oxide sapphire crystal there exists impurities of iron and chromium. These iron and chromium atoms replace individual aluminium or oxygen atoms within the crystal lattice to prevent the crystal from being absolutely pure.

For all those interested, an extremely pure sapphire crystal the
size of your fist is worth $10,000 US dollars, even more expensive than a sapphire you might find in Tiffany & Co or Cartier. This is for mainly one reason, and that is because its impurities are down to parts per billion—the most pure sapphire one can acquire. Even though they are extremely pure, the impurities are what makes it valuable to quantum physicists.

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Daniel and his FQM group utilise these rare impurities in a process called Whispering Gallery Mode Spectroscopy. They excite these crystals by shining microwave signals of different wavelengths and frequencies into the crystal in order to measure their resonance.

A way of explaining resonance is by blowing across the lid of a bottle. When the right amount of water is in the bottle, a nice sound will be made giving a very specific frequency and thus exciting a resonance mode. This is essentially what is being done with the crystals. Except that instead of being a vibration resonance, it is an electromagnetic resonance, and believe it or not, the resonances of sapphire crystals are very high. This is an explanation Daniel proposes to illustrate the quality of these resonances. “If a guitar had the same resonance as a sapphire crystal, the guitar string would play for 3 months.”

Daniel is testing how these different impurities and different concentrations of impurities will affect the resonance of these crystals. Whilst there are several groups around the world studying these impurities, Daniel and his colleagues differ by being the only group in the world to experiment on such a wide range of crystals and impurities.

By testing the effects of impurities on the resonance of the crystals, Daniel determines its “strong coupling.”

“Strong Coupling” put simply is the interactions between microwave light and the electrons in the impurities of the crystals. This is very strongly related to the idea of quantum computers where something (in this case the electrons in the impurities) can be both “up” and “down” at the same time. With the continuation of these experiments, the FQM research group will proceed to find ways of storing information on the impurities which will link the chain to the development of quantum memory and quantum computing.

Although sapphire crystals can operate at high temperatures, their qualities as an outstanding resonator only occur at extremely low temperatures. This is why Daniel must use a dilution fridge in order to conduct his experiments. Don't be fooled however, a dilution fridge is far from what you would find in your kitchen.

Imagine standing in a room with a temperature of 0 degrees celsius. It's cold, but with the right clothing, bearable. In that same room, now dial the temperature down to -50 degrees and this would freeze your whole body within a minute. Take this even further, much further. All the way down to -273.143 degrees Celsius and this is the temperature the crystals must go down to. This temperature is just 0.007 degrees off 0 Kelvin which is the absolute coldest that anything can go. It is so cold in fact that it takes two whole days for the dilution fridge to get the crystals down to this temperature.

These dilution fridges are used in cryogenics, which is the study of materials at extremely low temperatures. Cryogenics dates back to WWII where scientists discovered that metals showed more resistance to factors if they had been exposed to freezing temperatures.

Hidden beneath all the containers known as vacuum cans (see images on page 3) is a spectacular looking fridge that consists of two phases of cooling. The first are compressor machines out the back of the lab which rapidly compress and expand helium gas in order to get the temperature down to 4 Kelvin. The second phase occurs in the dilution fridge itself where Helium 3, an isotope of helium worth $2000 per litre, is distilled off Helium 4. The Helium 3 then
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crosses a phase boundary deep in the fridge called the mixing chamber. This finally brings the temperature down to 7 milliKelvin, just a few thousandths of a degree off the absolute coldest temperature. This process allows the fridge to attain its freezing climate.

Although the dilution fridge is the main part of the process, there is still much more Daniel must do to conduct an experiment. Testing on impurities and crystals also involve tasks ranging from basic maintenance and upkeep of lab machinery to designing blueprints for workshop engineers. Prior to using the dilution fridge, Daniel would prepare for testing in the clean room or by modelling and simulating experiments. Actually conducting the experiment in the fridge could take anywhere between 2 days and 6 weeks. That being said, once the test is finished, Daniel would still have to process and analyse the data. As you can see, his typical day is not a typical day at all and there is always something that needs to be done.

Luckily for Daniel, this is exactly what keeps him pushing forward in his experiments with impurities. He describes his love for physics and everyday work as “I like knowing how things work. If something doesn't work, I want to know why.” Daniel’s career in physics began after he took a degree in computer and mathematical sciences and discovered that physics was in fact his passion. After completing a PhD in developing microwave lasers via the use of sapphire crystals in 2012, Daniel is now a Postdoctoral Research Associate at UWA.

When thinking of what makes the perfect crystal we usually think of size, weight, aesthetics as well as the price tag, but never the impurities. After all, impurities make something impure right?

And even though this is true, the impurities are somehow still the single most valuable aspect of crystals that have the potential to change the world forever. By cooling crystals down to extreme temperatures and shooting microwave signals to excite them, Daniel says, “We hope that our study of impurities in crystals will help others in the field make advances in quantum computing and other technologies that may rely on these crystals.”

Quantum computing, although studied in great detail has not yet been applied to the real world. But once it is, it will revolutionise technology as well as the world we live in. Quantum computing is a treasure chest that we have already discovered, however the right key has not yet been found and thus it is up to the likes of Daniel and other quantum physicists to find that key. Much like the impurities, the answers are still unclear, but much like the transparency of the sapphire crystals, how we are going to get there is clear, crystal clear.
On the 31st July, the School hosted a function to celebrate the career of Jim Williams to date. It marked the transition of Jim’s "employment status" from Winthrop Professor to Emeritus Professor - he does not like the "r" word. I was careful to say "career to date", because Jim plans to continue his research and teaching unabated, and so retirement is indeed a misnomer in his case. It was very pleasing that many of Jim’s former PhD students and postdocs could come to share a drink with him and with staff and students from the School. We were honoured that the former Vice Chancellor, Alan Robson, was able to attend. Jim’s first Honours student at UWA, David Sampson, now Director of the Centre for Microscopy, Characterisation and Analysis, gave some amusing anecdotes about his time in Jim’s lab. Jim in turn gave a very moving speech about his time (to date!) at UWA.

Jim’s arrived at UWA in 1980 to take up the Chair in Physics in the then Department of Physics, having been a Reader in Physics at Queens University in Belfast prior to that. He served three consecutive terms as Head of Department in the period 1980 – 1990, during which time he did much to focus the Department on the need to build research focus and strength. He also served in 1992 as Dean of the Faculty of Science, and in 1993 as Head of the Division of Agriculture and Science. Whilst a passionate teacher, Jim’s main impact at UWA has been via research. He is recognized internationally for undertaking groundbreaking precision measurements, requiring specialist apparatus he designs himself (and fabricated in the School of Physics workshop). At UWA, he held continuous funding from the ARC in the period 1980 – 2013, attracting more than $12 million. In addition to Discovery and LIEF grants and their predecessors, Jim was awarded the first ARC Special Investigator Award, valued at $1.75 million for the period 1998 – 2002. He was also a CI in the ARC Centre of Excellence for Antimatter Matter Studies, leading the UWA node. To date he has over 220 research publications in peer refereed journals and over 150 conference presentations. He has supervised a large number of PhD and Honours students, some of whom hold senior academic positions in leading universities around the world, and high level positions in government and industry.

So the first 35 years of Jim’s career at UWA have been stellar, and we look forward to Jim’s continued involvement in the life of the School well into the future.

Speaking of celebrations, the School will be hosting its annual Alumni event at 6pm on Friday 23rd October in the Atrium of the Physics Building. Last year’s event saw over 100 Physics Alumni gather for drinks and the opportunity to catch up with old friends and with current graduated students and staff. This year’s event will feature an appearance by a very special guest and some brief presentations about current developments in the School, including some of the exciting research being undertaken. Please mark the date in your diaries, and I hope to see you there.