Quantum Tunneling – TRIUMF Saturday Morning Lecture – March 28th, 2008

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What we will look at ...

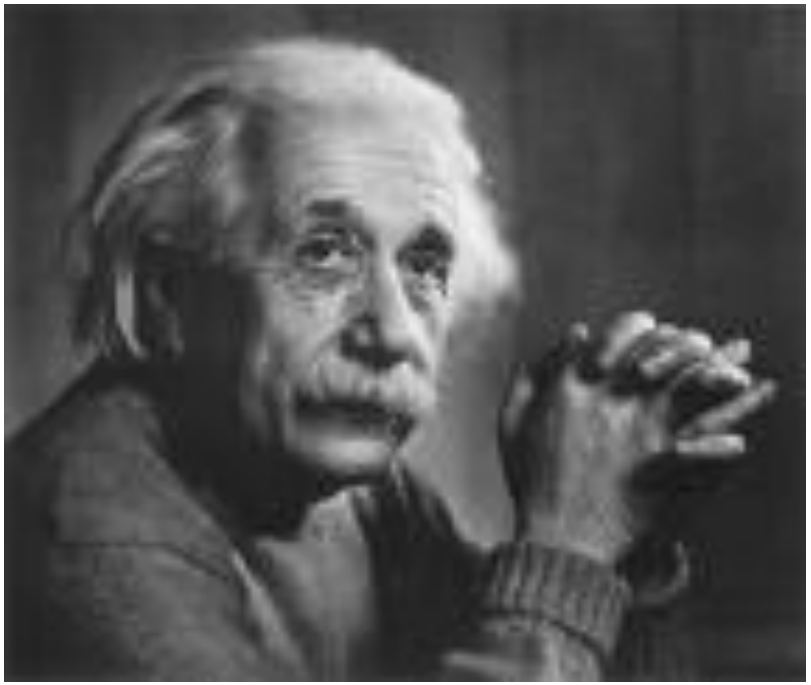
- The "*Big Picture*" behind the very small ...
- Feynman and "*Room at the Bottom*" – Think Small!
- Nanotechnology
- George Gamow and Quantum Tunneling

I will be unconventional !

- In talking about *Quantum Tunneling* I will talk about applications before I talk in any detail about the theory of Quantum Tunneling.

- Tunneling is a quantum effect and is only seen in structures nanometer or smaller in scale!

The "*Big Picture*" behind the very small world of QM



Why are we interested in Quantum Mechanics?

Is it just because it is Weird and Interesting?

How big a role does Quantum Mechanics play in our lives?

How much wealth created in the past century draws from QM?

- A) 5 per cent
- B) 15 per cent
- C) 25 percent?

A Surprising Answer!

- During the last 100 years, about 25 % of new wealth draws from Quantum Mechanics.

- In this, the 21st century, we can expect upwards of 50% of new wealth to come from Quantum Mechanics!

… *In Them hills* …

- In the past …

"there's ***Gold*** in them hills!"

Au → $ 800 / Troy Ounce.

- Today … "there's ***Silicon*** in them Computer Chips!"

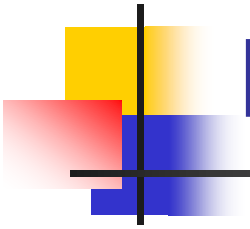
CPU → $ 300,000 /Troy Ounce!

Nanotechnology in near future → $ 30,000,000 / Troy Ounce

Then and now ...

- Twenty years ago, 80% of computer chips used in North America were made here (... 20% were imported).
- Today 20% of computer chips used in North America are made here.
- The recent economic down-turn is tied to changes in international trade that can just as well be measured in the flow of computer chips.
- North America needs to address this!

Choosing to focus on Quantum Mechanics in 2009 TSML series



In putting together the TSML the speakers all recognize that Quantum Mechanics is an ***interesting subject***.

We also recognize that learning about Quantum Mechanics is not just an interesting pastime.

QM - "A Good Investment!"

TAKE STOCK In
Quantum Mechanics Inc.

Founding Board

Albert Einstein
Arthur Schawlow
Richard Feynman
George Gamow
Bill Unruh (UBC)
and many others ...

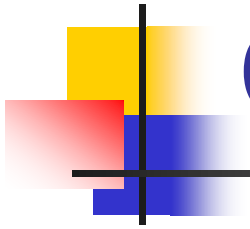
Those of you thinking about careers will find that learning about Quantum Mechanics and its many Applications will open career paths.

The members of QM Inc. have created more wealth than any Rockefeller or J.P. Morgan!

The Next Time ....

- Much of the technology we take for granted in our day to day life, are direct applications of Quantum Mechanics.
- Unfortunately, very little of this technology is made in Canada! We import over $ 65 billion in high technology each year to Canada.
- For instance, the next time you visit the hospital ... Look around!
- X-Ray / CAT Scanners
- Computers
- MRI (NMR)
- Electrocardiograph

“Better Living through Quantum Mechanics ...”

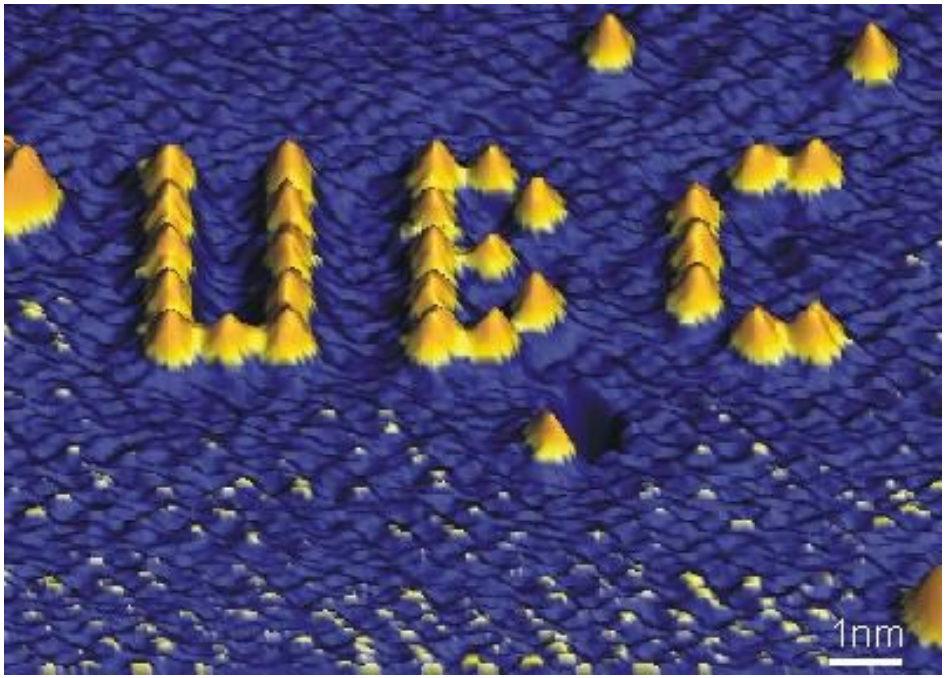


- Our Quality of Life depends on the physics of Quantum Mechanics and its many applications.

Membership in the Quantum Mechanics Inc. Syndicate ...

- A highly respected and exclusive gathering of exceptionally thinkers ... They are "*People who think outside the conventional*."
- You have to study hard to become a member ... and be good at mathematics.
- You have to be able to "***Think Small***"

UBC a great place to "*Think Small!*"



- Shown here is the smallest University Logo ever written.
- Letters are a mere 2 nm wide and consist of CO molecules on a Cu surface, individually positioned and imaged.

Next speaker … Dr. Unruh, a founding member of QM Inc.

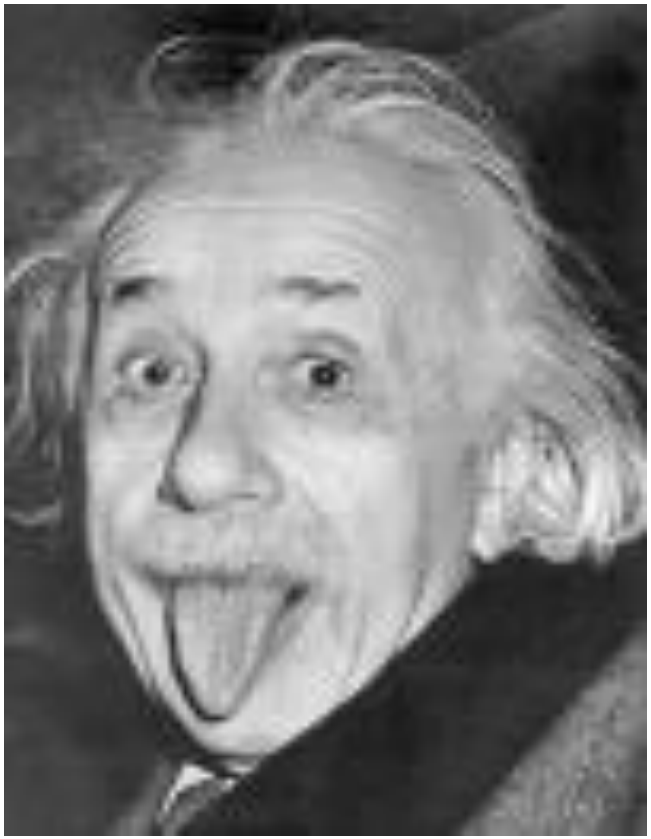
- Dr. Bill Unruh with his old Ph.D. supervisor, Dr. John Wheeler, at the Wheeler banquet in 2002 at Princeton.
- Dr. Unruh is the closest we can come to a "***Canadian Einstein***"

What's in the "Quantum Mechanic's" Tool Kit

- An "*Auto Mechanic*" brings a box of tools to work ...
- What does a "*Quantum Mechanic*" bring to their work?
- If you are into *THEORY* ... a pad of paper a pencil and mathematics ...
- If you are into *EXPERIMENT* ... some really interesting equipment like TRIUMF and mathematics ...

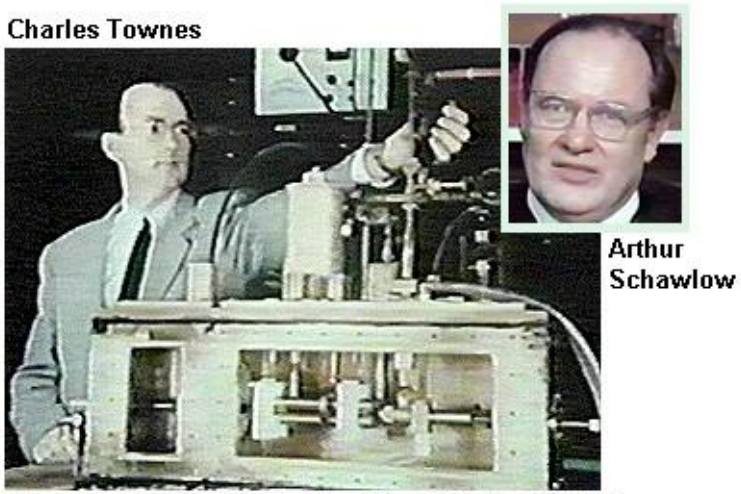
Albert Einstein – One of the First "Quantum Mechanics"

- We have all heard of Lasers ... *Light Amplification by Stimulated Emission of Radiation*.
- But did you know that theoretical work in Quantum Mechanics by Albert Einstein in 1916 is what preceeded the invention of the Laser in 1960!



Before the Laser came the Maser!

- The MASER – Microwave Amplification by Stimulated Emission of Radiation was invented in 1954.
- Used in Telecommunications and Atomic Clocks

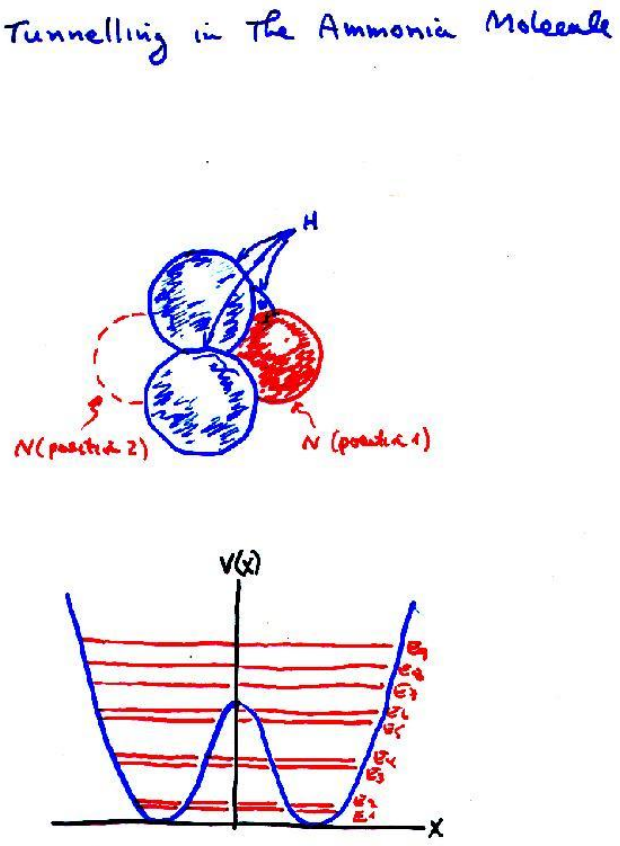


Microwave Amplification by Stimulated Emission of Radiation
The "MASER" ... predecessor to the LASER, 1954

Which of these Nobel Prize Winners is Canadian?

Masers are used to study Quantum Tunneling!

- Ammonia (NH_3) ia a tetrahedron molecule.
- Ammonia has energy states in two adjacent wells, that are coupled one to the other.
- Quantum tunneling occurs between the states!

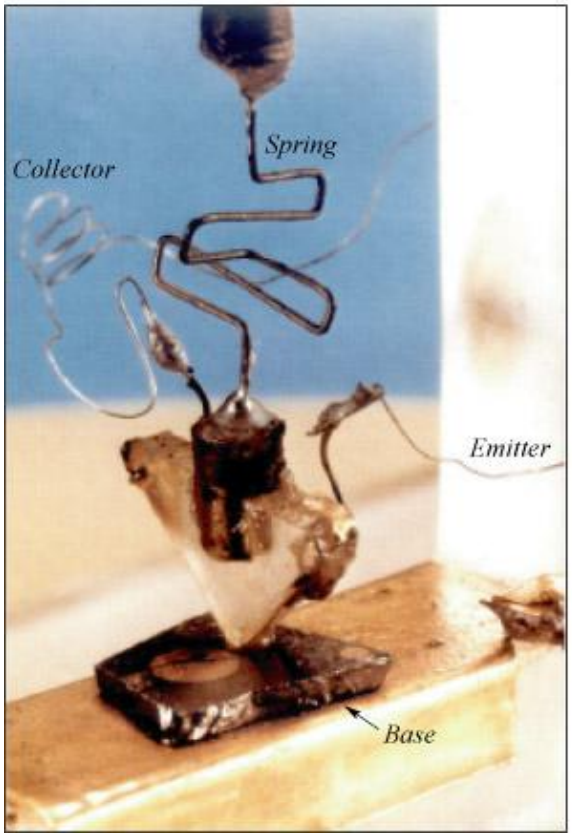


Before the Maser came the Transistor ... A microstructure!

The first point contact transistor

William Shockley, John Bardeen, and Walter Brattain

Bell Laboratories, Murray Hill, New Jersey (1947)



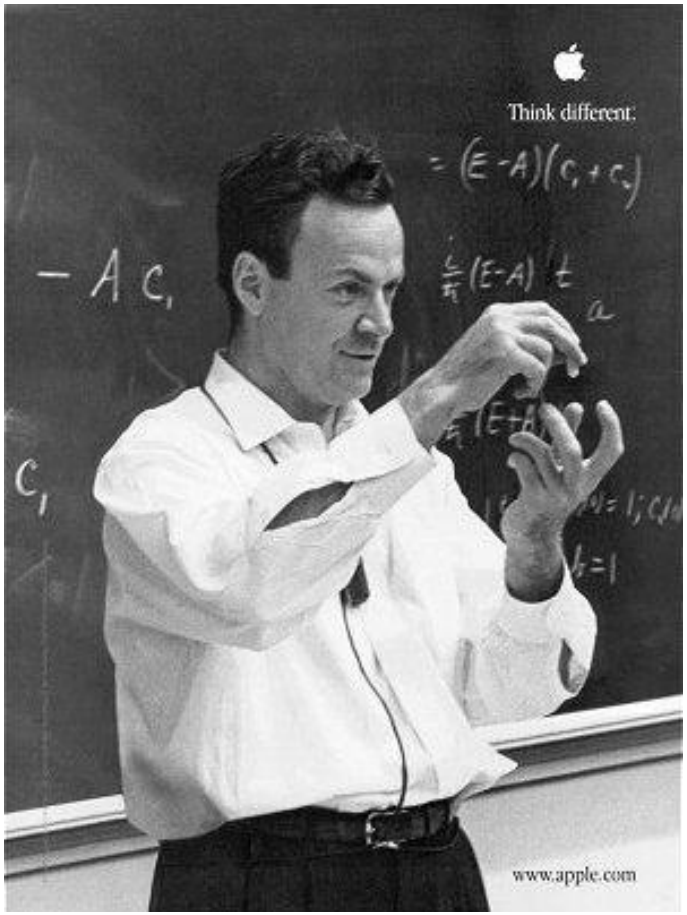
Transistors Physics – an evolving applied science

- The *Point Contact Transistor* came out of developments in war time Radar to improve on the old style tungsten whisker radio detector (in fact the PCT looks like a tungsten whisker detector on steroids).
- The *Junction (npn or pnp) Transistor* came next and is an improvement over the old triode radio tube.
- The MOSFET – Metal Oxide Field Effect Transistor was developed in the 1970's and is the type of transistor in wide spread use at the present time.

Think Small … Think Quantum Mechanics

- In the 20th century size and economies of scale have driven technology …
- The future will be different!
- It may be left to high efficiency nanostructures to best define the 21st Century …
- It may be left to ***Nanotechnology***

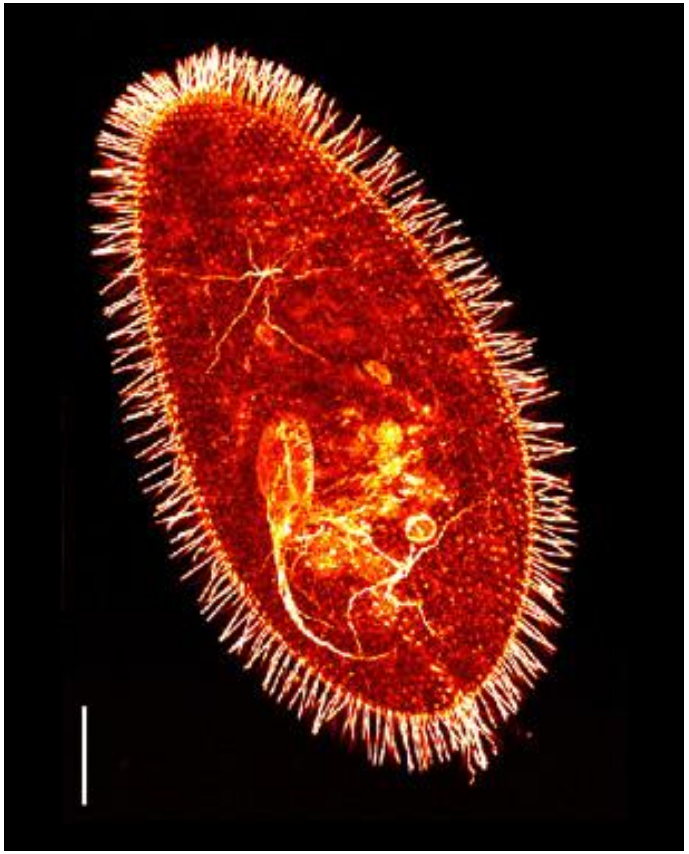
Richard Feynman, the father of Nanotechnology



- Feynman's 1959 APS Talk "*Room at the Bottom*."
- Feynman's definition of Nanotechnology: *"the problem of manipulating and controlling things on a small scale."*
- If you look closely you see he is explaining quantum tunneling!

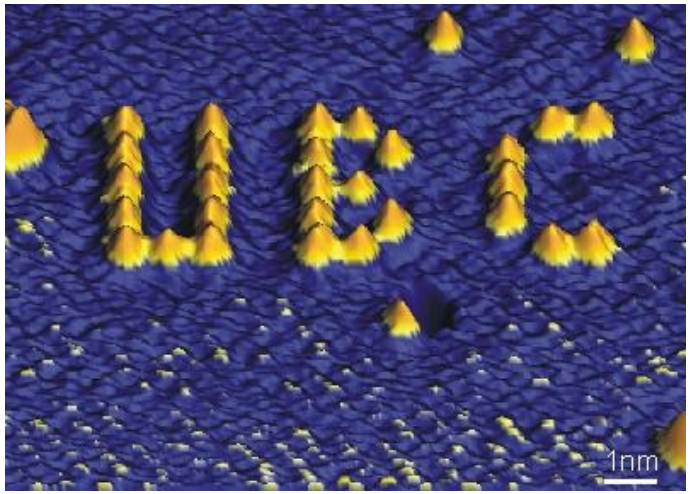
From Micro to Nano ...

- Microstructures you can see with the eye or a simple microscope.
- Biologists are familiar with micromachines made of organic materials.



Nanos are very small (nm)!

- The UBC LOGO was made and is seen using an electron microscope (the colour is computer generated).
- FYI, the first fully functional Electron Microscope was built at the U of T in 1938 by Hillier and Prebus!



This electron microscope helped to solve the puzzle of the influenza outbreak that killed 20 million people after World War I.

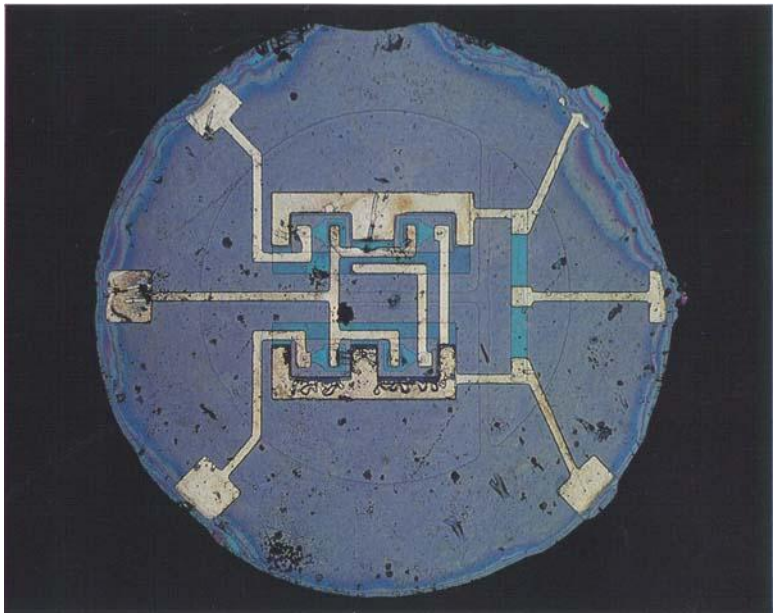
Feynman - A Father of the Nano Revolution

- In his 1959 talk "*Room at the Bottom*" he describes how photoetching can be used to make copies of a master document, so that all human knowledge could be stored on a card the size of a post card!

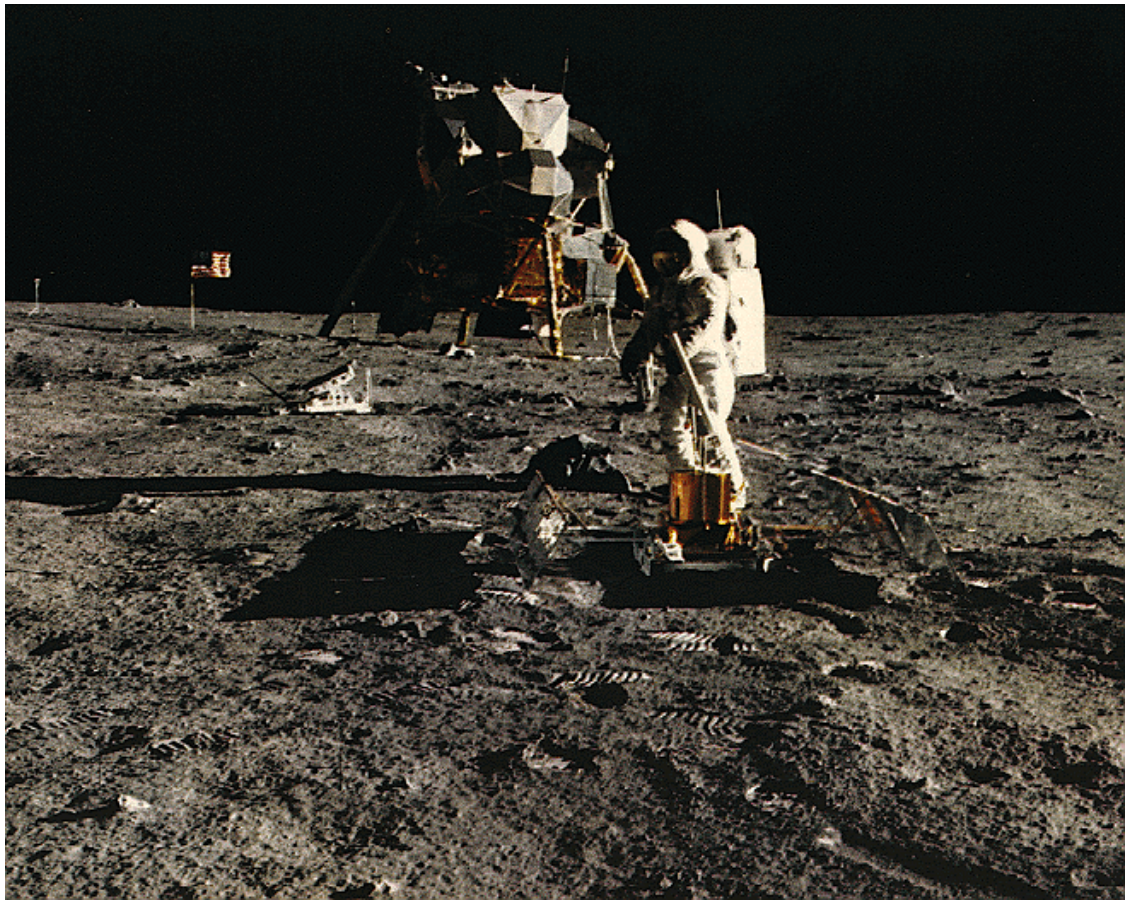
- He also explained the basic principles that would result in the CD and DVD disc 25 years later!

The Planar Integrated Circuit!

- The transistor was invented in 1947.
- Feynman gave his famous talk in 1959.
- By 1961 photoetching and the Integrated Circuit came into being (Fairchild Planar IC).



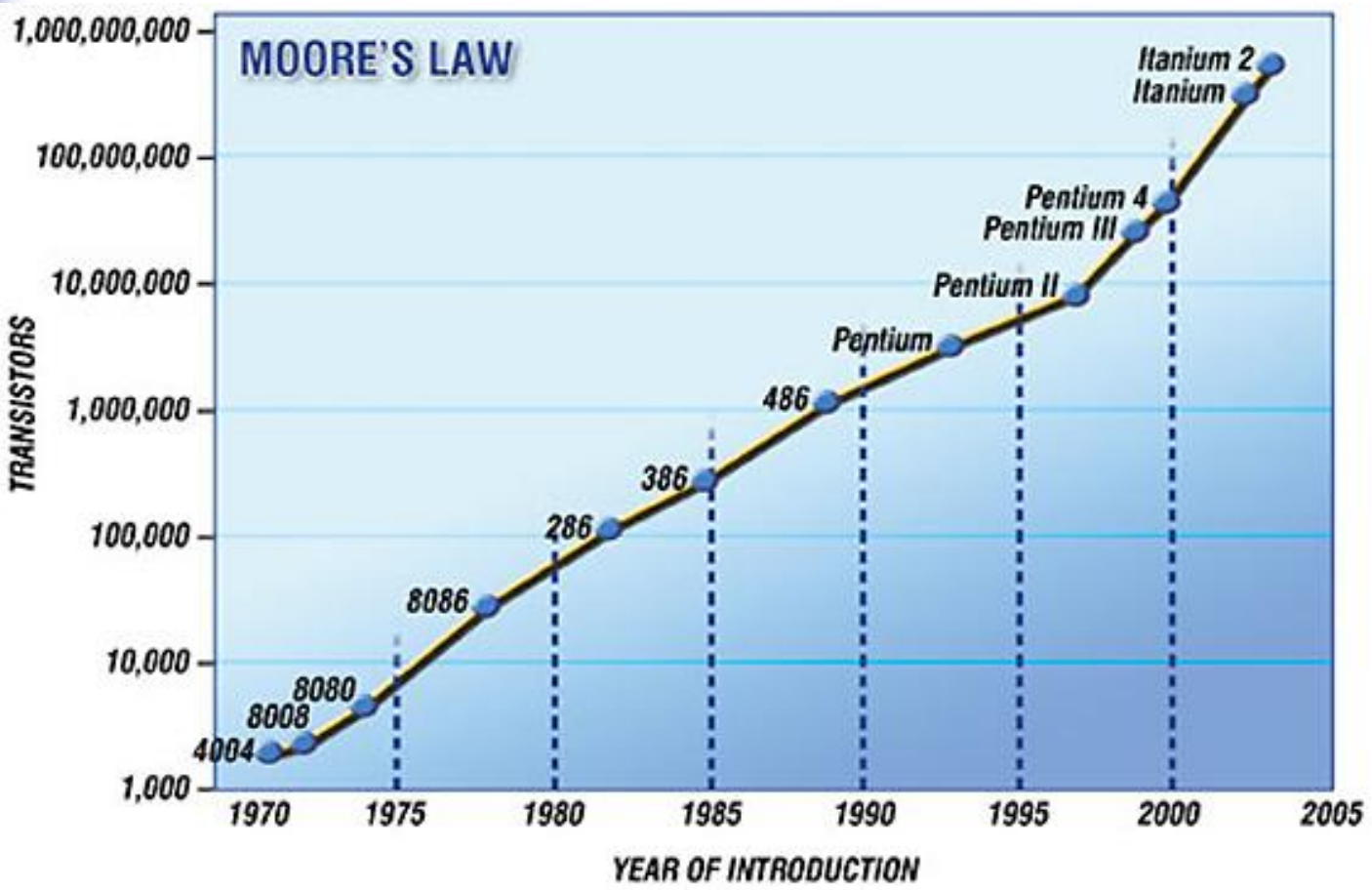
The IC is what ultimately landed Man on the Moon in 1969



We shall return ...

- Within ten years human beings will ***Return to the Moon***.
- this time ... ***We will be there to stay***
- And by 2025 ... we may be on ***Mars with permanent colonies*** as well. Nanotechnology will get us there!

Moore's Law (1965) - Intel



Moore Deserves a Nobel Prize

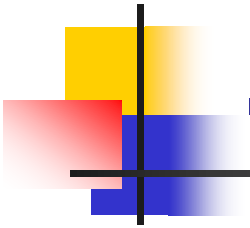
- I think Moore deserves a Nobel Prize ...
- But not in Physics ... ***in Economics***!
- His work and that of his colleagues has generated more wealth than any Rockefeller or J.P. Morgan!

Feynman ... Miniature machines ... Fun to make ...

"How many times when you are working on something frustratingly tiny like your wife's wrist watch, have you said to yourself, "If I could only train an ant to do this!" What I would like to suggest is the possibility of training an ant to train a mite to do this. What are the possibilities of small but movable machines? They may or may not be useful, but they surely would be fun to make!"

"*Room at the Bottom*." Richard Feynman

A challenge for you the builder … Build a small machine



- If you like designing and building a small machine from scratch … With your own hands and tools around the house …
- What would be the smallest machine you think you could build?

What ever you made by hand

- Nano means a billionth of a metre.
- What ever you make by hand, it will be millions of times bigger than a nanomachine!

An Excellent practical application of Nanotechnology

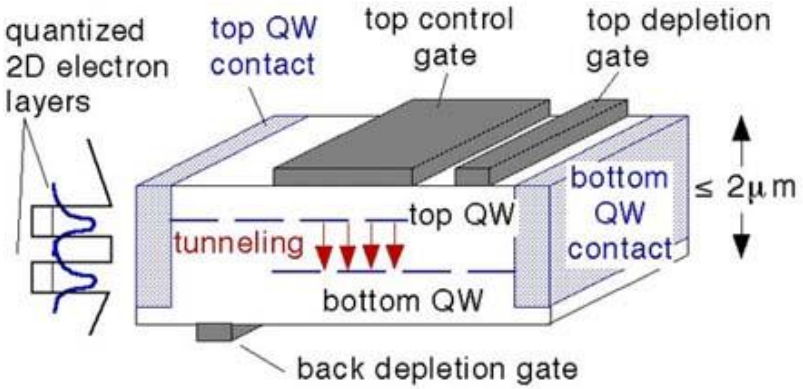
- In theory you can tune an antenna to match the frequency of the incoming electromagnetic radiation.
- This is how a radio works!
- A good practical challenge in Nanotechnology is to build an antenna array that is tuned to absorb ***Visible or IR Light*** and convert it directly into stored ***Electrical Power***.

Patrick's Nano Challenge!

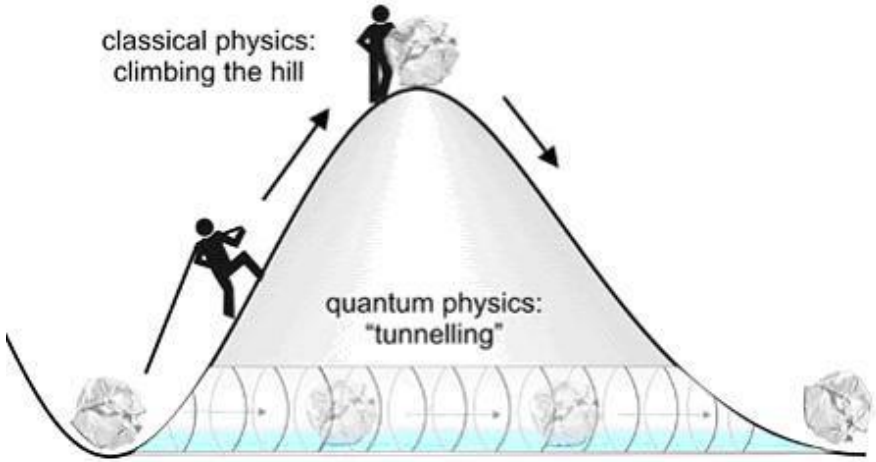
- I challenge the clever and creative to make a Nano-array of antenna tuned to Visible or IR frequencies that will absorb, convert to electricity and store 50 % or more of the incoming electromagnetic radiation, but be an ***OUD*** (***Over-Unity Device*** makes available for use more energy than it requires to function).
- Your Reward for this achievement will be a ***Nobel Prize in Physics***!

Quantum Tunneling Transistor

- To make such an ***Over Unity Device*** (OUD) possible may require the use of a new invention, the quantum tunneling transistor...



Going through the hill! ...

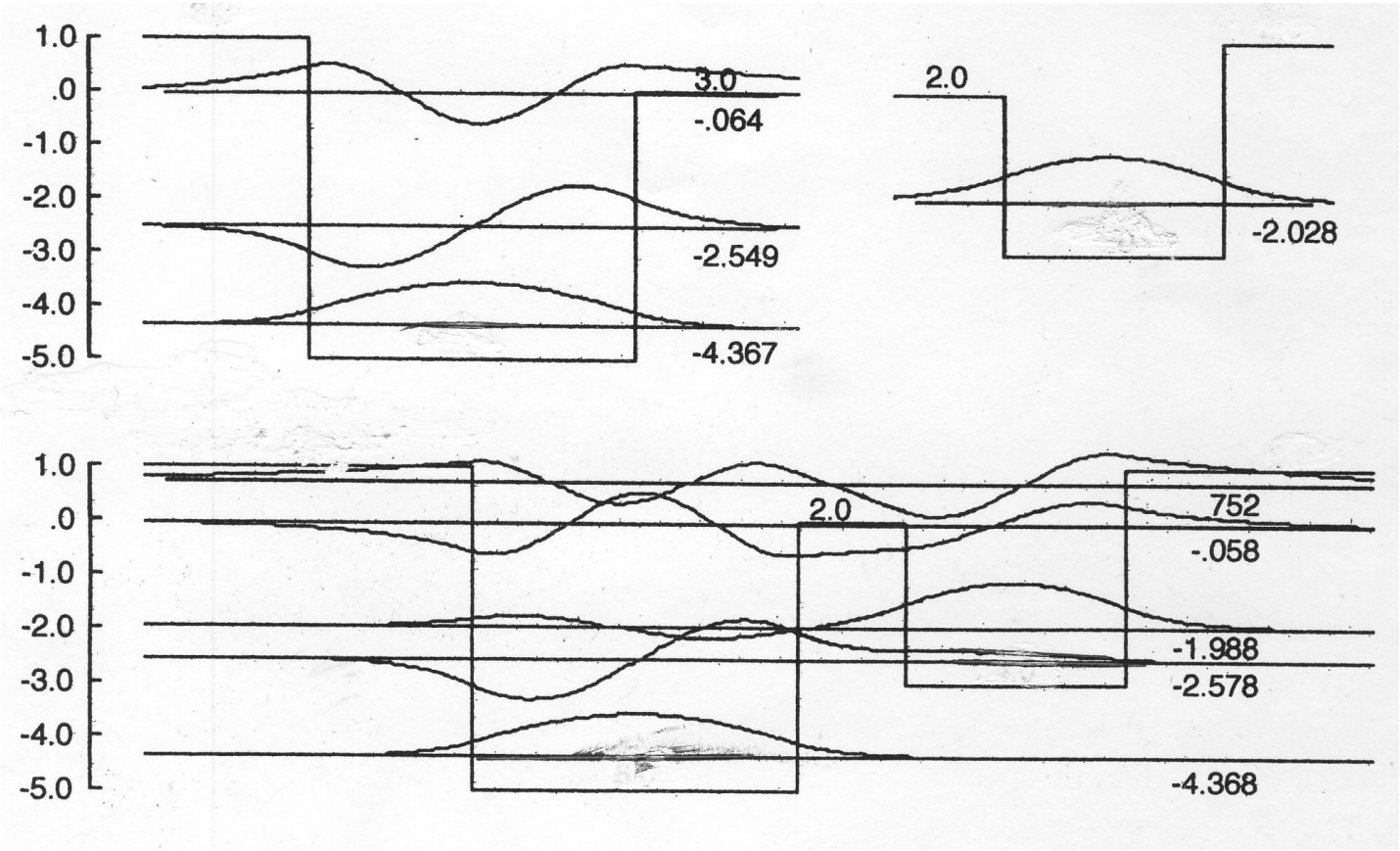


- A "***Quantum Well***" is like a hill.
- In classical physics you can only go "over the top."
- In a quantum system you can sometimes "tunnel through the hill itself!"

Is it really that strange?

- If the hill were made of dry oatmeal flakes and you were throwing a base ball at it ...
- At some point up near the top of the hill it becomes possible for the ball to go through the hill!
- In a quantum well, the oatmeal is the individual quanta of energy that makes up the wall of the potential well
- In the heavier elements a particle cluster in the nuclei like a Helium atom will, as it hits the well, at some point begin to poke through!

Wave functions and Tunneling



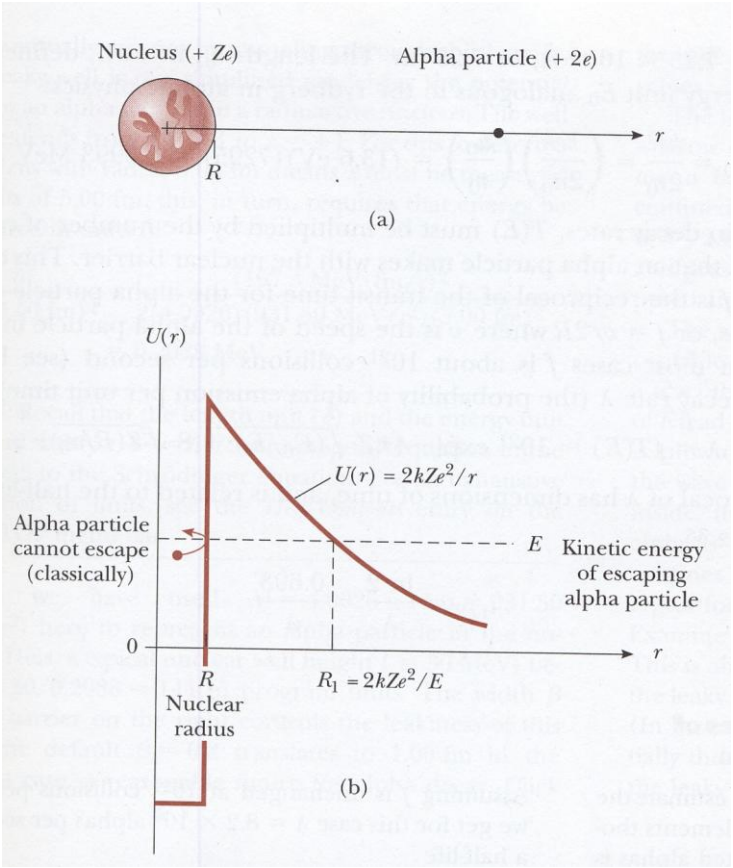
George Gamow ... and Quantum Tunneling

- The theory of alpha decay via quantum tunneling (1928)
- Thermonuclear tunneling (1932)
- Liquid Drop Model (1938)
- The Origins of the Elements
- Big Bang (1948)
- Cosmic Microwave Background (CMB)

The Three Musketeers ...

- George Gamow studied under Alexander Friedman who took Einstein's Theory of General Relativity and applied it to the Universe and Cosmology.
- As a student Gamow was a close friend to *Lev Landau* and *Dmitri Ivanenko* ... They were called "The Three Musketeers ...
- After Landau was arrested ... Gamow packed a bag and walked out of Soviet Russia!"

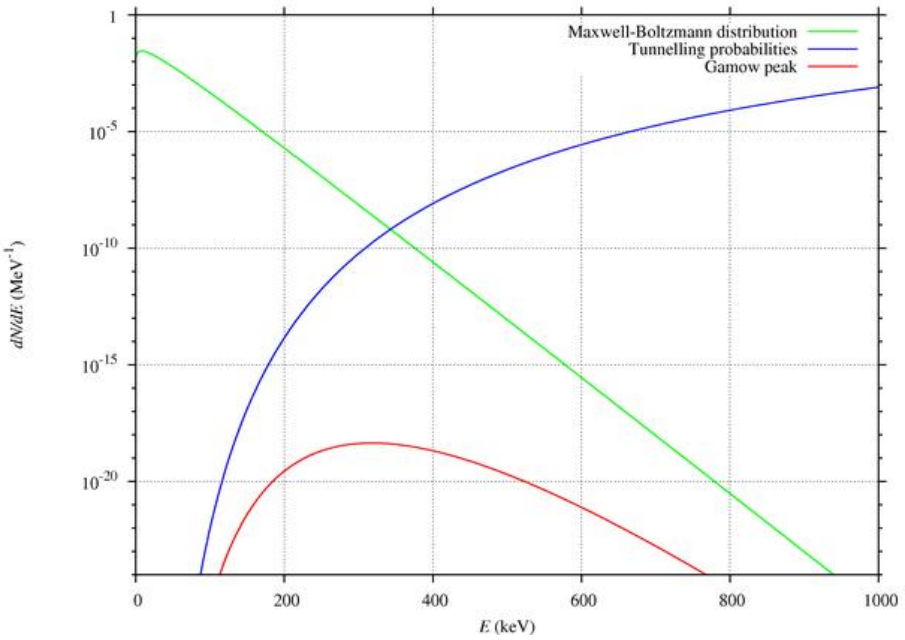
Quantum Tunneling in Alpha Decay ...



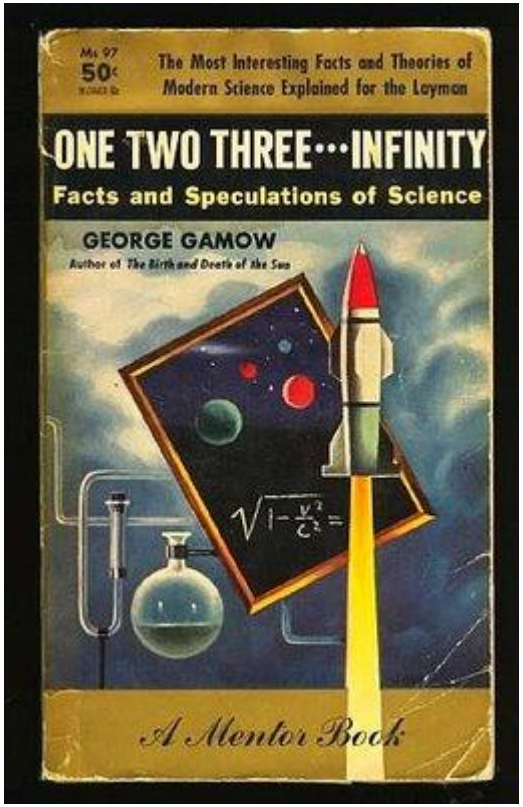
- In some nuclei, before it leaves the nucleus, an alpha particle is moving back and forth bumping into the wall of the nuclear potential well
- Each time it does it has a small probability to escape
- Eventually it does.

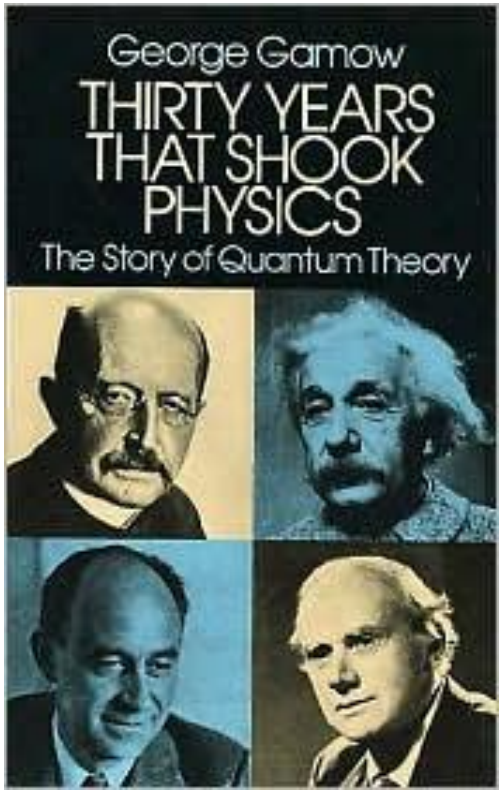
Quantum Tunneling in Thermonuclear Reactions ..

- In the centre of stars the hydrogen gas is very hot ... But has a small probability to get close enough to fuse. they bump into each other often.
- Eventually through quantum tunneling the hydrogen fuse to become deuterons ... then helium ... Nuclear fusion makes life possible on earth
- The little bump is known as the Gamow peak.



Good books By George Gamow



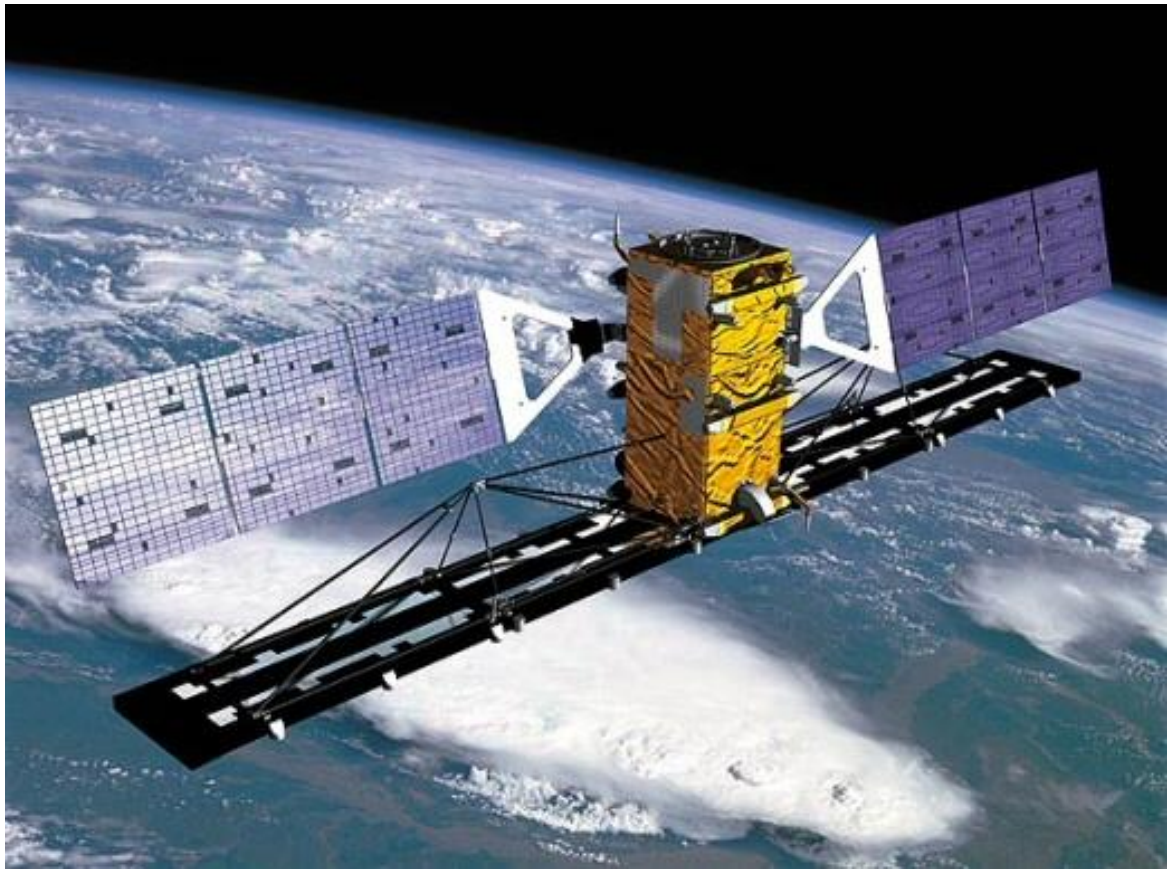


The Big Picture of the Very Small world of Quantum Mechanics

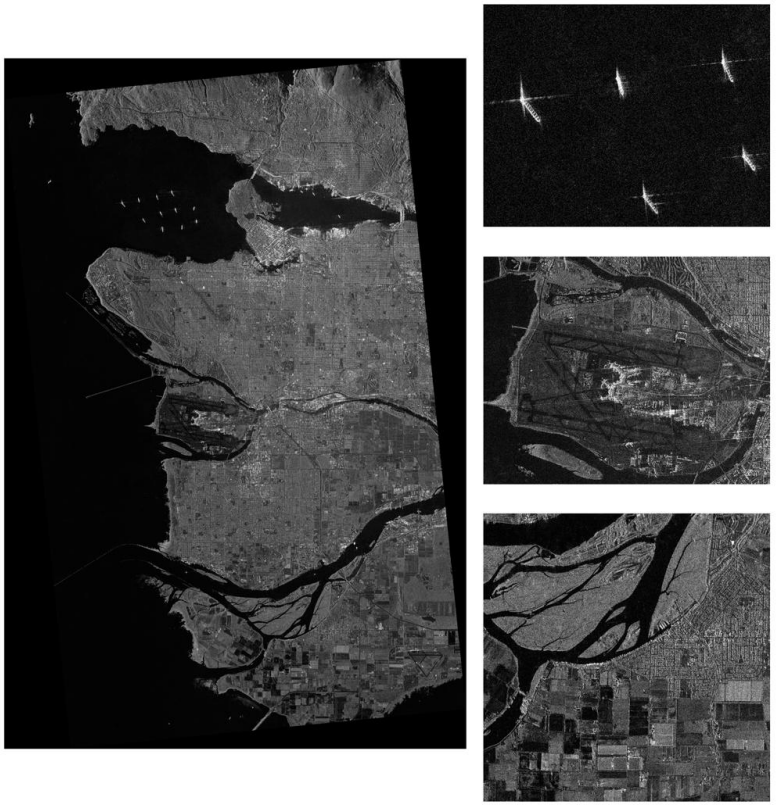
- We need to appreciate *"Better Living Through Quantum Mechanics ..."*

- A Good Canadian Example of Quantum Mechanics at Work ... Radarsat- 2 and the Upcoming Radarsat Constellation Mission (RCM).

Radarsat – 2 : Gem in the SAR Satellite Constellation (CUPJ)



A look from space made possible by Quantum Mechanics!

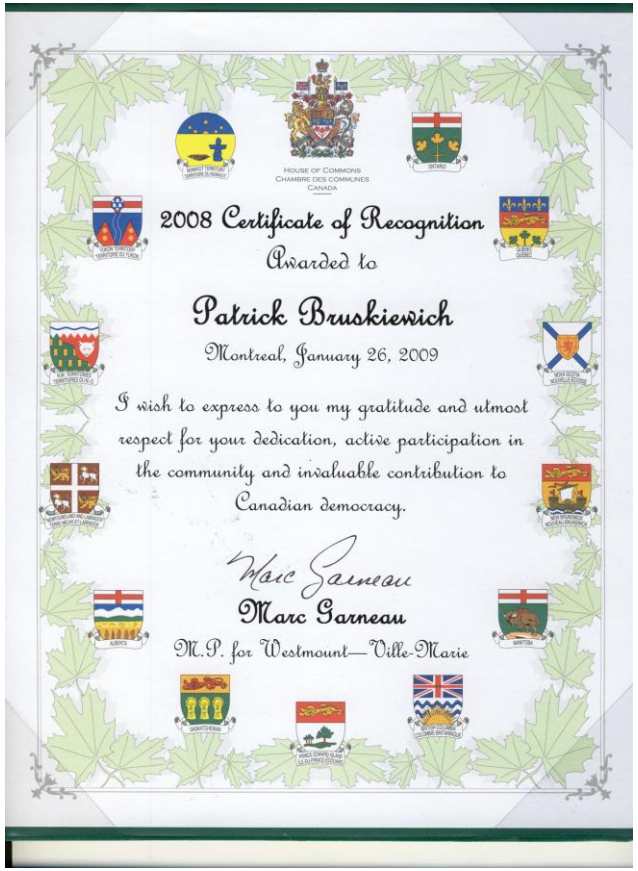


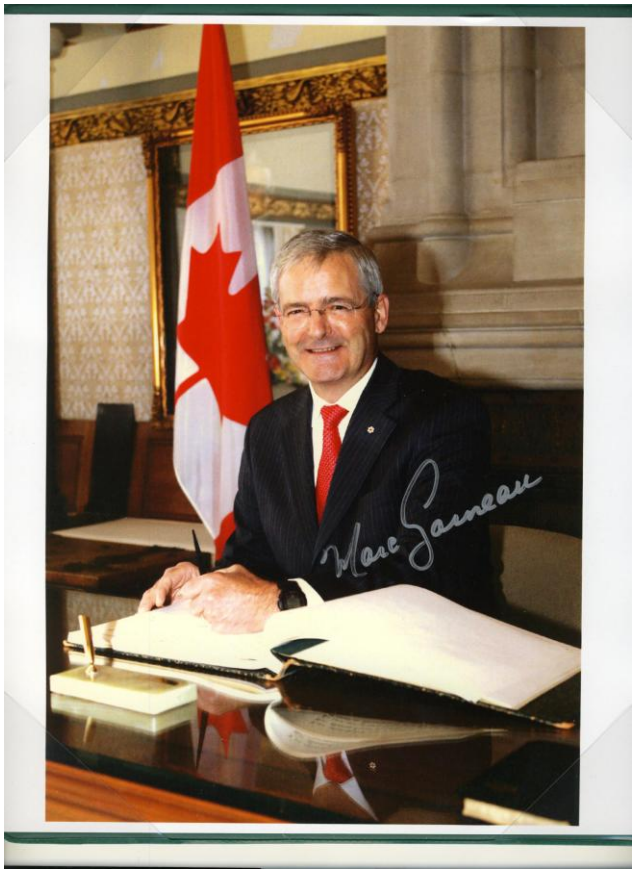
The UN and ICEOO

- My colleagues and I have recommended to the Secretary General of the United Nations, the Rt. Hon. Prime Minister of Canada and the new US President that it is time to create a new UN organization, using Radarsat as a key asset ... Patterned after ICAO.

- The ***International Civil Earth Observation Organization*** (ICEOO)

A public Thank you to Dr. Garneau (see interview in CUPJ)





My solemn hope ...

- It is my solemn hope that one day a Canadian will walk on the Moon and on Mars ...
- Perhaps it will be one of you!
- Work hard and Think Small, become a member of QM Inc. if you want to get there!

Thank you

- The website for the Canadian Undergraduate Physics Journal is www.cupj.ca.

- I can be reached at

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