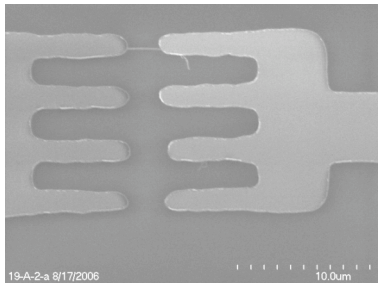
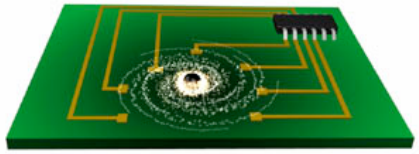
Darn cold nano-stuff

(or why the hell did McGill needed to dig holes in the Rurtherford basement)

Guillaume Gervais

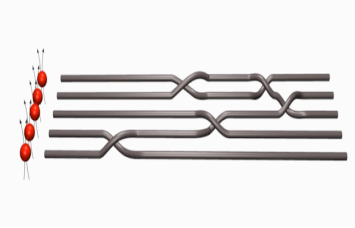
Ultra-Low Temperature
Condensed Matter Experiment

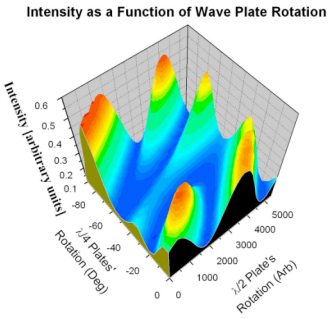




Just because I don't care doesn't mean I don't understand

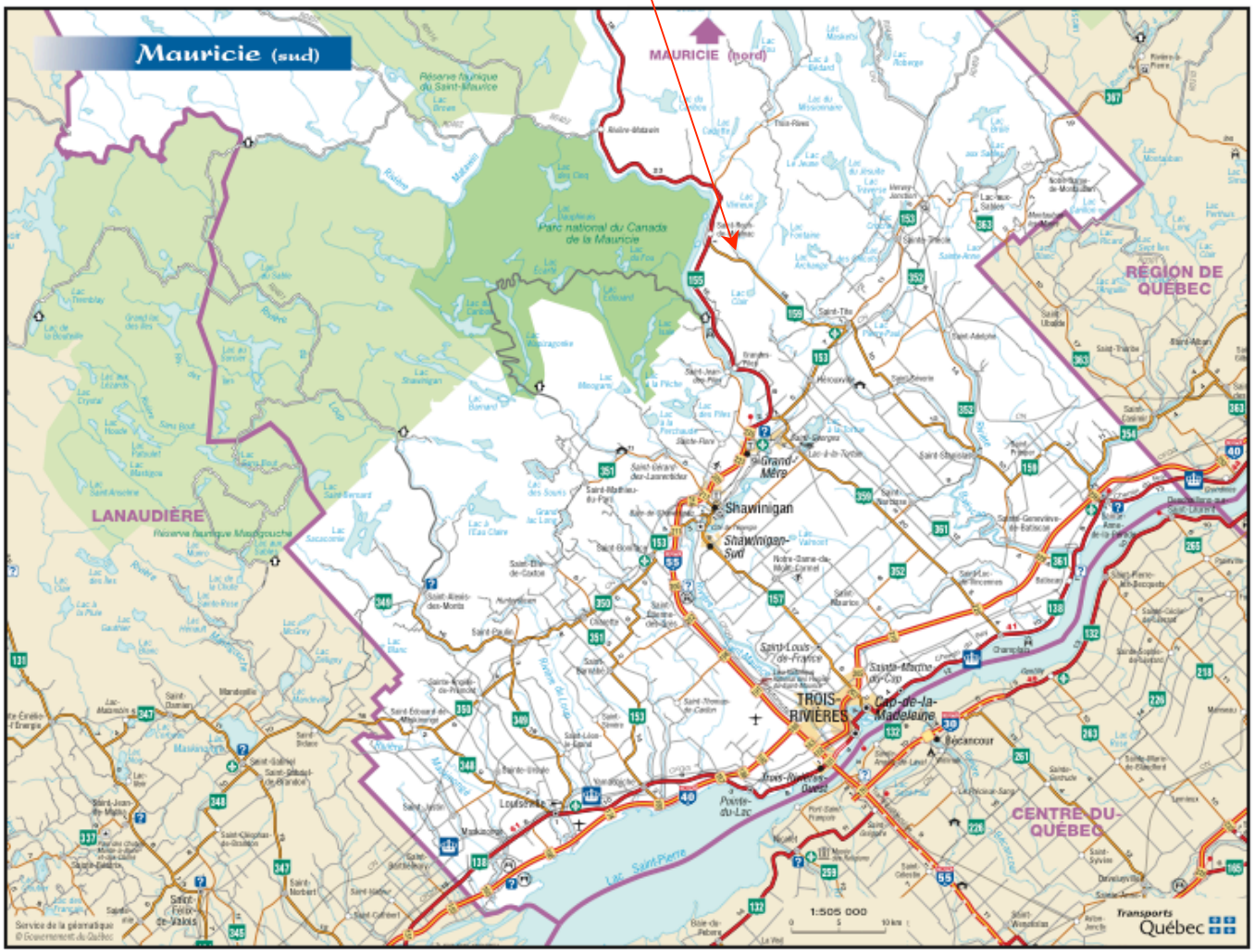
-Homer





Chapter 1: Who's this guy digging holes and making so much noise in the basement….?!?

G^2 grew up near St-Tite, Qc….



In what sorta castle did he live, anyway?

*G^2 begun his humble education at the glorious **Universite du Rang Sud**, in St-Tite, Qc….*

G^2 facts #1: G^2 hated school all along (and schools hated him even more)

But then came the motorcycle…anyway

G² at 16 prior to racing JSR (Jean-sebastien Roy) in Valley Junction,Qc

(p.s. I totally chose the wrong career, JSR IS FAMOUS)

G² facts #2: Motorcycles are much more fun than schools. But you gotta fix it yourself

But did this guy go afterward anyway?

G^2 in a tiny village in-between Istanbul and Ankara

G^2 facts #3: Turkish kids will teach you a heck of a lot more than teachers….

But what was this guy doing there anyway?

G^2 in a desertic area on the anatolean plateau in Turkey, running out of water, and telling the Little Prince, what the hell am I (f&%$ing) doing here.*

G^2 facts #4: It's ok to get lost in the desert for as long as you find the Little Prince…

I like sports

***G² facts #5**: Extreme sports/adventures is just as fun as extreme physics…and it's much more so than schools…*

So what was doing this guy this Summer anyway?

He was climbing a hill at near 13,000 ft altitude in Sante Fe, New Mexico, inJuly….

I know you guys are dying to see my latest darling…

Here she is!

My sweet Yamaha R6 with 130+ horses, red line @ 16,500+ RPM and top speed of 277 km/h for only 355lbs….

Wanted!!! policeman to make accurate doppler shift measurement of her top speed…

G^2 facts #6: It's ok to have a fast bike for as long as you stay alive on it.

So how good (…bad) is this guy academic track record ?

1978: Ecole elementaire de St-Tite
I 'failed' my first transcript ever in School cause I was unable to speak. They did not care I could do math, but they failed me because I COULD NOT SPEAK. I simply had nothing to say…..

1989: Ecole Polyvalente Paul Lejeune de St Tite
The director threatened to kick me out because of I was racing motorbikes on the school premisses. He just did not understand how fun it was.

1995: B.Sc. Universite de Sherbrooke
The dept. Chair did not like me which made it real hard to get any fellowship through…(yeah, being straight "A"ain't enough in our business)

1996-1997: M.Sc. McMaster University
My supervisor wrote a bad letter of recommendation "on my behalf". Darn……(yeah, being straight "A" an write paper fast ain't enough in our business)

1997-1998: Michigan State University
I fell in love after 2 weeks and quit that school after 8 months for Chicago.
Got a good letter this time cause americans like new students that write papers real fast…

1998-2002: Ph.d, Northwestern University
The dept. Chair did not like me cause there is a couple of classes I never took…..I simply was busy with research… My supervisor loved it tho, cause I was writing lots'a papers….

2002-2005 post-doctoral work, Columbia/Princeton (USA)
I was the laugh of the lab cause I wanted to do "resistive NMR" and I even had to dig the darn pit I needed for the experiment
My supervisors, Horst and Dan, loved my ideas tho…(for as long as I were to succeed)

2005-now assistant prof, McGill U
No comment.

So Guillaume came to McGill , and recruited the greatest student

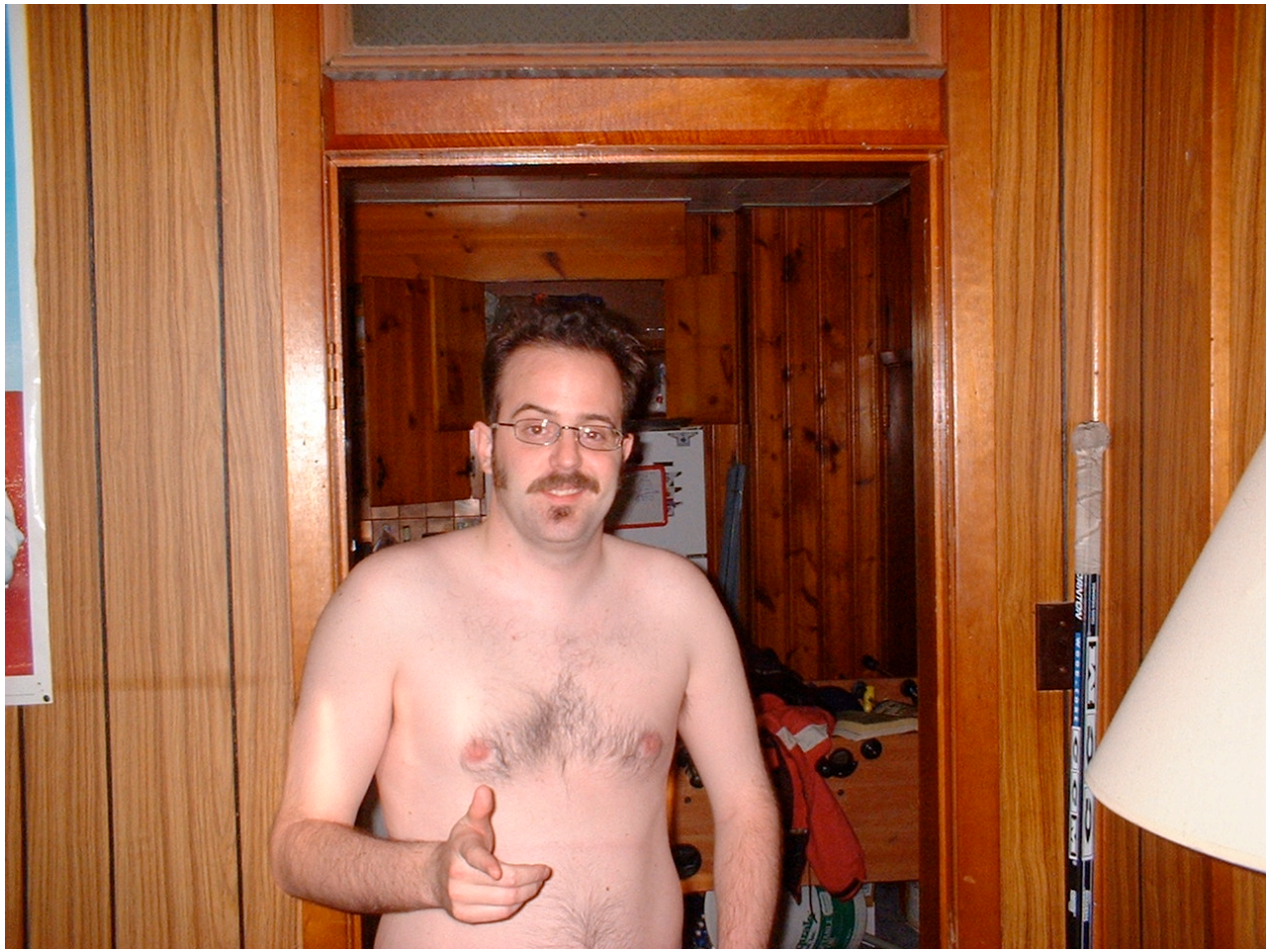
First came Cory Dean……

So Guillaume came to McGill , and recruited the greatest student

First came Cory Dean……(again)

So Guillaume came to McGill , and recruited the greatest student

First came Cory Dean……(again)



So Guillaume came to McGill , and recruited the greatest student

….and then came James Hedberg

So Guillaume came to McGill , and recruited the greatest student

….and then came James Hedberg (again)

So Guillaume came to McGill , and recruited the greatest student

….and then came James Hedberg (again)

G² facts #7: in our lab, we welcome personality disorders….

So Guillaume teaches them the beauty of experimental physics with "Fine Literature "

Electron Band Structure In Germanium, My Ass

Abstract: The exponential dependence of resistivity on temperature in germanium is found to be a great big lie. My careful theoretical modeling and painstaking experimentation reveal 1) that my equipment is crap, as are all the available texts on the subject and 2) that this whole exercise was a complete waste of my time.

Introduction

Electrons in germanium are confined to well-defined energy bands that are separated by "forbidden regions" of zero charge-carrier density. You can read about it yourself if you want to, although I don't recommend it. You'll have to wade through an obtuse, convoluted discussion about considering an arbitrary number of non-coupled harmonic-oscillator potentials and taking limits and so on. The upshot is that if you heat up a sample of germanium, electrons will jump from a non-conductive energy band to a conductive one, thereby creating a measurable change in resistivity. This relation between temperature and resistivity can be shown to be exponential in certain temperature regimes by waving your hands and chanting "to first order".

Experiment procedure

I sifted through the box of germanium crystals and chose the one that appeared to be the least cracked. Then I soldered wires onto the crystal in the spots shown in figure 2b of Lab Handout 32. Do you have any idea how hard it is to solder wires to germanium? I'll tell you: real goddamn hard. The solder simply won't stick, and you can forget about getting any of the grad students in the solid state labs to help you out.

Once the wires were in place, I attached them as appropriate to the second-rate equipment I scavenged from the back of the lab, none of which worked properly. I soon wised up and swiped replacements from the well-stocked research labs. This is how they treat undergrads around here: they give you broken tools and then don't understand why you don't get any results.

In order to control the temperature of the germanium, I attached the crystal to a copper rod, the upper end of which was attached to a heating coil and the lower end of which was dipped in a thermos of liquid nitrogen. Midway through the project, the thermos began leaking. That's right: I pay a cool ten grand a quarter to come here, and yet they can't spare the five bucks to ensure that I have a working thermos.

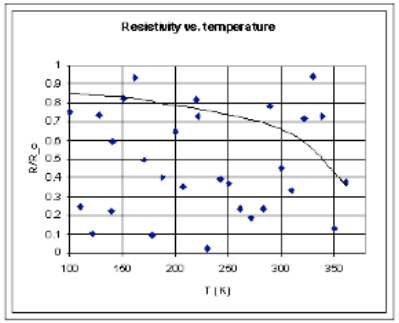


Fig. 1: Check this shit out.

Results

Check this shit out (Fig. 1). That's bonafide, 100%-real data, my friends. I took it myself over the course of two weeks. And this was not a leisurely two weeks, either; I busted my ass day and night in order to provide you with nothing but the best data possible. Now, let's look a bit more closely at this data, remembering that it is absolutely first-rate. Do you see the exponential dependence? I sure don't. I see a bunch of crap.

Electron Band Structure In Germanium, My Ass

Abstract: The exponential dependence of resistivity on temperature in germanium is found to be a great big lie. My careful theoretical modeling and painstaking experimentation reveal 1) that my equipment is crap, as are all the available texts on the subject and 2) that this whole exercise was a complete waste of my time.

Introduction

Electrons in germanium are confined to well-defined energy bands that are separated by "forbidden regions" of zero charge-carrier density. You can read about it yourself if you want to, although I don't recommend it. You'll have to wade through an obtuse, convoluted discussion about considering an arbitrary number of non-coupled harmonic-oscillator potentials and taking limits and so on. The upshot is that if you heat up a sample of germanium, electrons will jump from a non-conductive energy band to a conductive one, thereby creating a measurable change in resistivity. This relation between temperature and resistivity can be shown to be exponential in certain temperature regimes by waving your hands and chanting "to first order".

Results

lts.

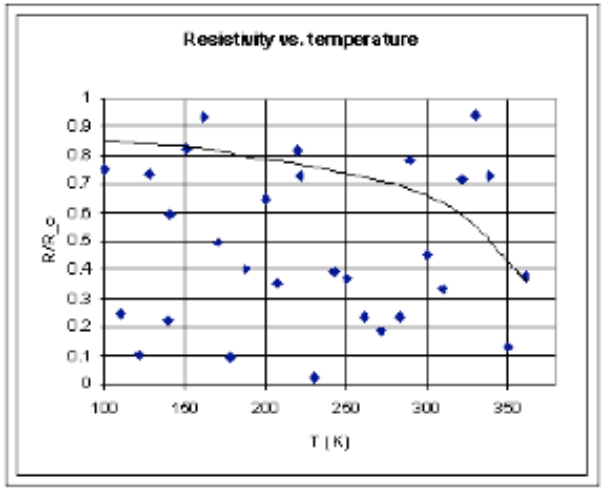
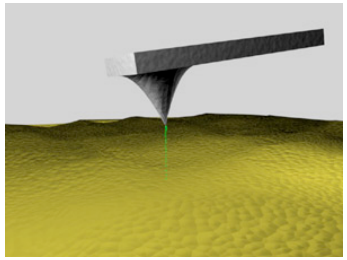


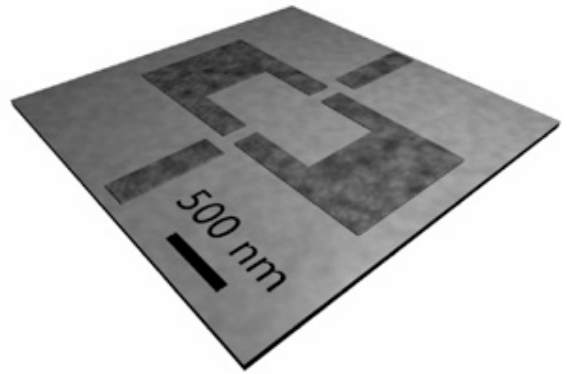
Fig. 1: Check this shit out.

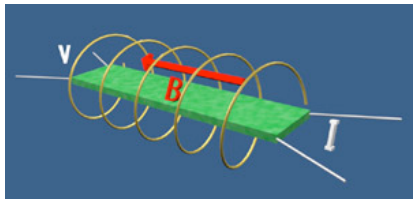
Check this shit out (Fig. 1). That's bonafide, 100%-real data, my friends. I took it myself over the course of two weeks. And this was not a leisurely two weeks, either; I busted my ass day and night in order to provide you with nothing but the best data possible. Now, let's look a bit more closely at this data, remembering that it is absolutely first-rate. Do you see the exponential dependence? I sure don't. I see a bunch of crap.

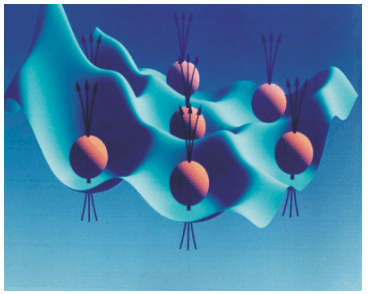
G² facts #8: experiment ain't always easy….

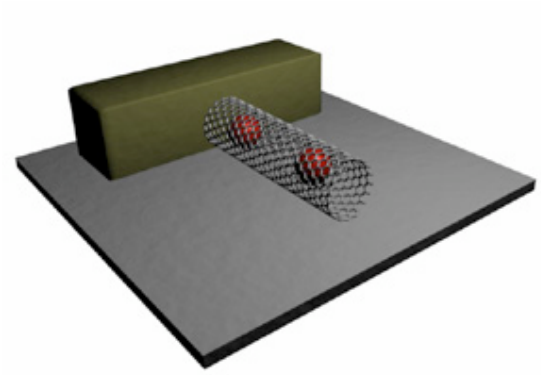
Chapter 2: So what's this guy doing now anyway?

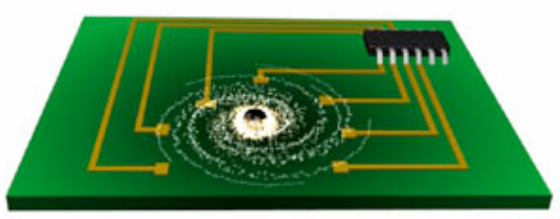






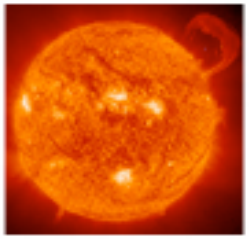


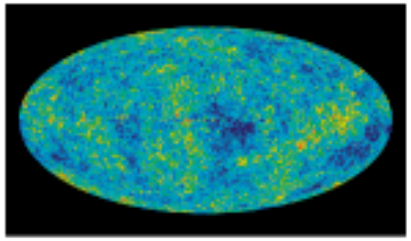


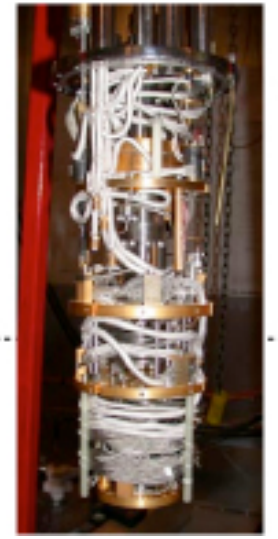


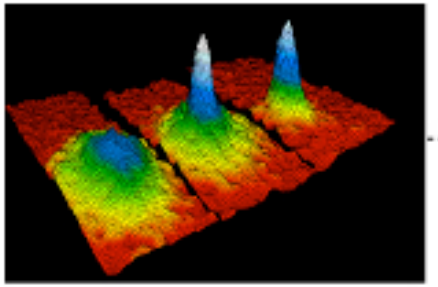
G^2 facts #9: The nano-stuff near T=0 sounds very cool

How cold is T=0, or how close can we get?









° Kelvin

10^{8}	nuclear explosion	*Robert, Jim, Guy…*
		Charles, Sanjeong
10^{7}	sun's interior	*Andrew* *Vicky, Bob*
		Maria, Paul, Roland,Peter, Brad,Martin
10^{1}	liquid Nitrogen	**You are here*
		Mark, Peter, Dominic
10^{0}	CMBR	*Gil,Matt, Peter, Dominic*
10^{-2}	dilution refrigerator	*Guilaume, Micheal*
10^{-4}		
10^{-8}	Bose-Einstein condensate	
10^{-10}	adiabatic nuclear demag	

T=0

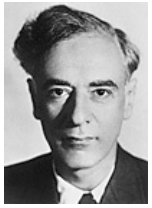
Aashish CLERK?(T<0)

World record: T~500 pK (Helsinki low-temperature lab)

Is the Physics near T=0 any interesting?

1913 Kemmerling-Onnes

"for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium"



1962 Lev Landau

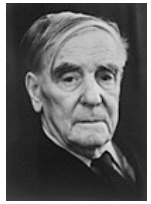
"for his pioneering theories for condensed matter, especially liquid helium"

1970 Bardeen, Cooper and Schrieffer

"for their jointly developed theory of superconductivity, usually called the BCS-theory"

1973 Josephson

"for his theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena which are generally known as the Josephson effects"



1978 Kapitza

"for his basic inventions and discoveries in the area of low-temperature physics"

1985 von Klitzing

"for the discovery of the quantized Hall effect"

1996 Osheroff, Richardson and Lee
"for their discovery of superfluidity in helium-3"

1997 Chu, Cohen-Tannoudji, and Phillips
"for development of methods to cool and trap atoms with laser light"

1998 Laughlin, Stormer and Tsui
"for their discovery of a new form of quantum fluid with fractionally charged excitations"

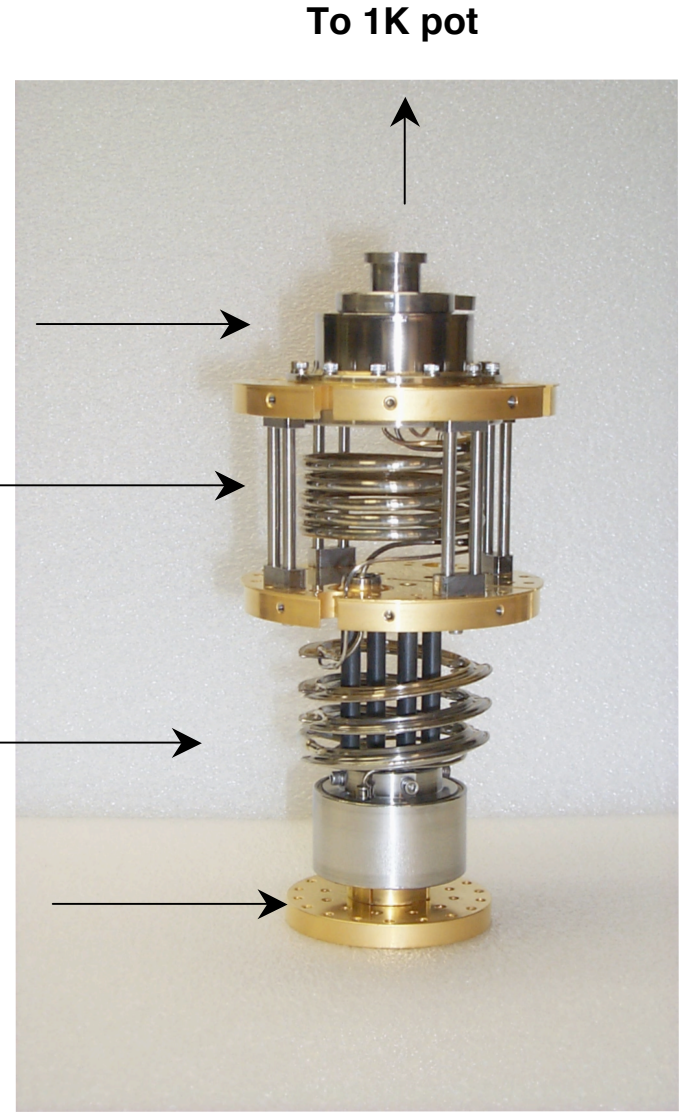
2001 Cornell, Ketterle, and Wieman
"for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the Condensates"

2003 Abrikosov, Ginzburg and Leggett
"for pioneering contributions to the theory of superconductors and superfluids"

2023 Dean, Laroche and Hedberg
"for bravely coping with the unreal aspects of the quantum nano-world, and equally bravely sustaining strong disagreements about the Nature of all this with their former Ph.D. advisor"

G^2 facts #10: You've got to disagree if you want to make advances…

How do you cool solids, liquids that cold?



To get cold, you also need dedicated grad students….

McGill Ph.D. student (and Queen's alumnus) Cory Dean working on a dilution refrigerator capable of reaching 8 mK

G^2 facts #11: Near T=0, plumbing is everything….

And you need to have their total respect

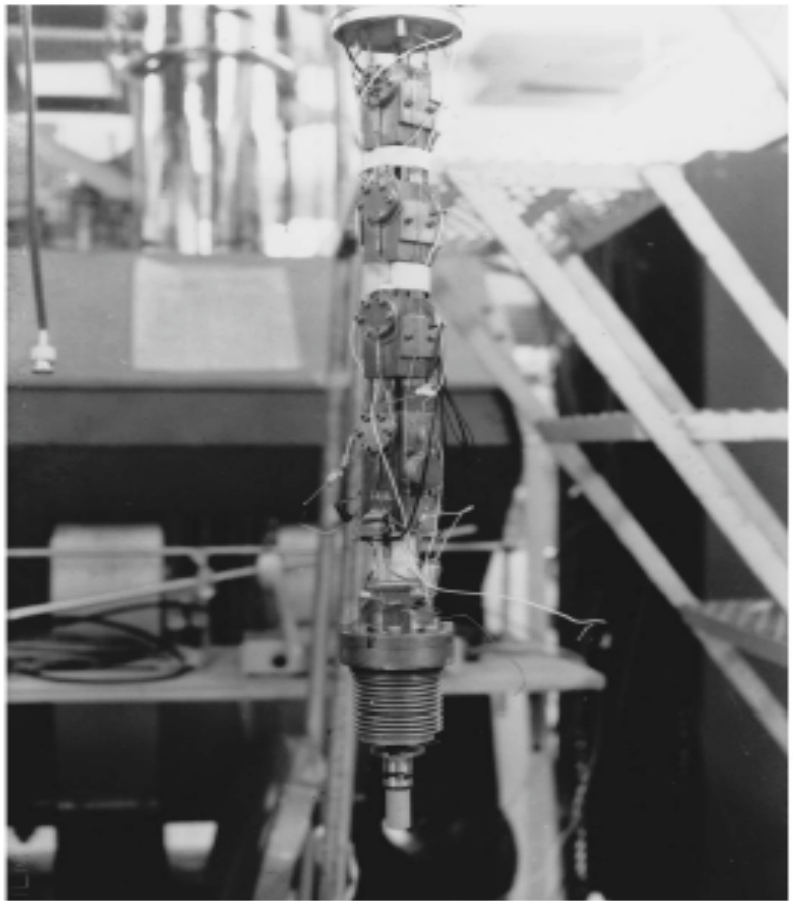
(i.e you cannot have them making fun of you at all)

G² facts #12:Students are not always nice.

Just remember that T =0 physics ain't always pretty…

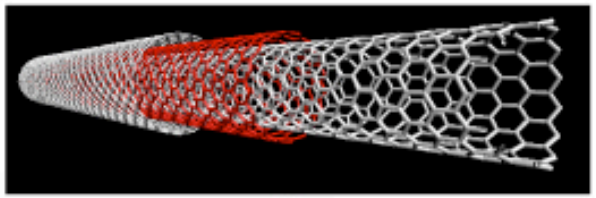
From D.D. Osheroff Nobel lecture:

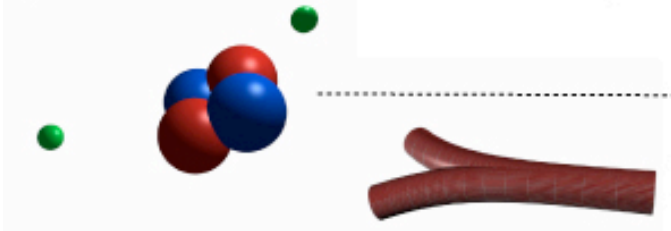
I cooled the cryostat back down on Dec. 21. By Dec. 24 I had gotten the new platinum NMR thermometer working and spent the next few days testing for thermal contact to the ^{3}He bath and for rf eddy current heating. By Christmas Eve I had reached the *A* transition, but left the lab early, at about 10 pm. I had hoped to use the same NMR coil to study the ^{3}He NMR signal, but the signal was very small. I finally found a ^{3}He NMR line at 1:55 am on New Year's night. It seemed pretty useless. I left the lab at about 3:00 am, and when I came in the next afternoon someone had written "Happy New Year, Doug" in the lab book. Two days later we compressed and found that very little solid ^{3}He formed between the platinum wires of the NMR thermometer. We could not use a single NMR coil to measure temperature and simultaneously study the ^{3}He NMR signal!



G^2 facts #13: Doug was a hard ass-working Ph.d student…

How small is this brave 'new' nano-world?





10^{21} zettameter — *ROBERT, Gil, Matt…*

10^{16} parsec — *Vicky, Andrew, Bob R…*

10^{3} kilometer — *Shaun…*

10^{0} meter — **You are here*

10^{-2} centimeter — *Maria*

Dominic, Martin, Jorge….

10^{-6} micron — *Paul, Mark….*

10^{-9} nanometer — *PETER, Roland, Aash, Hong, Brad..*

John, Bob Moore…

10^{-15} femtometer — *Charles, Jean, Sanjeon..*

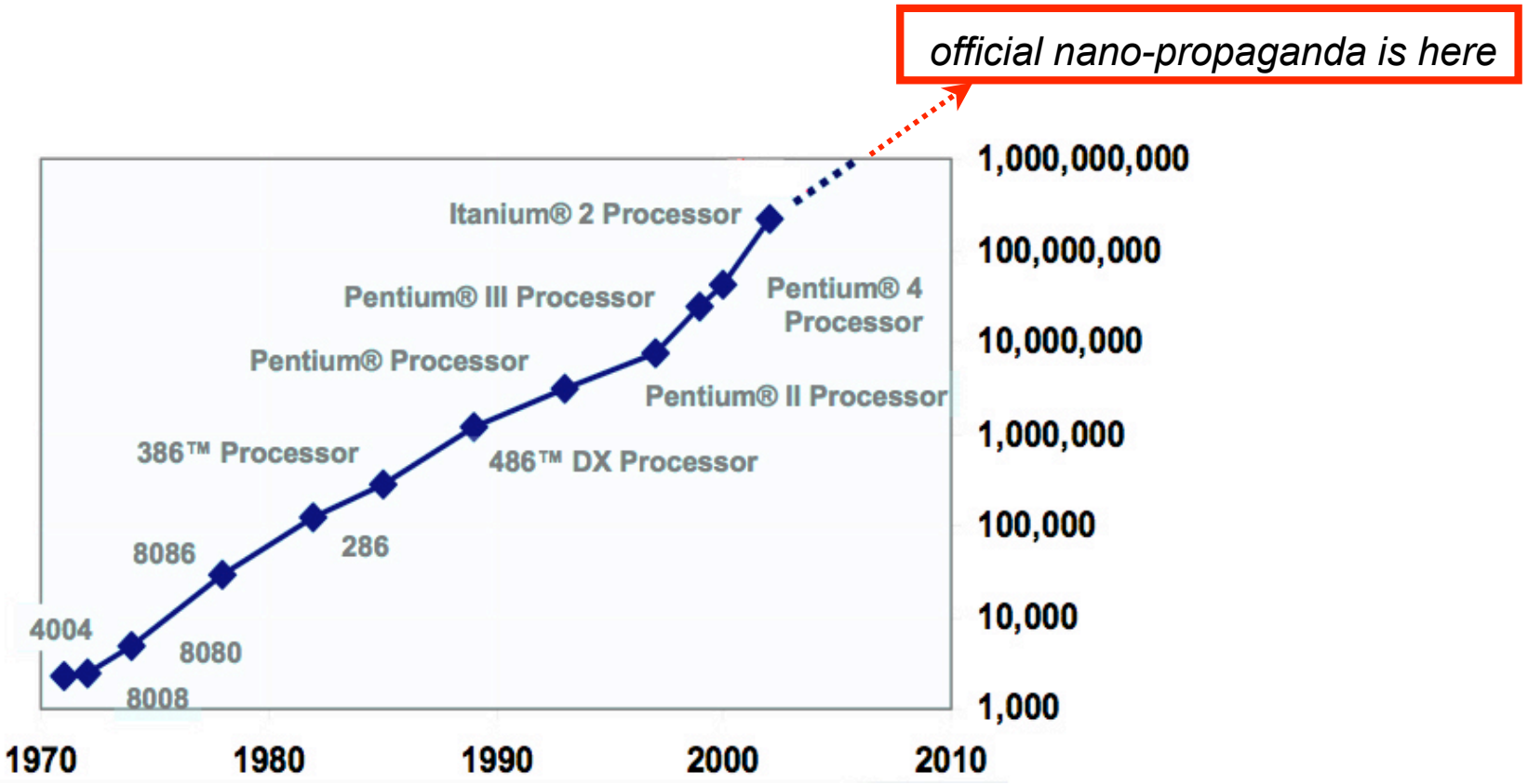
Brigitte, Steven, Guy..

10^{-35} planck length — *Jim, Keshav, ROBERT???*

G^2 facts #13:Robert spans 56+ orders of magnitudes…. Cool……!.

Why should we even care that it's 'nano'?

From a technological standpoint, micro-electronics's reaching the limit…..



Yeah, and so what?

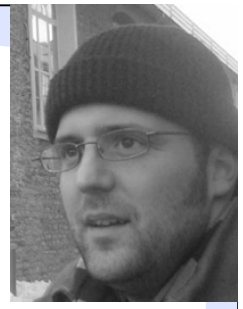
'At the nanoscale, liquids and solids, electrons included, often undergo different, even strange new behaviours resulting from a competition between fluctuations, interactions, confinement and disorder'

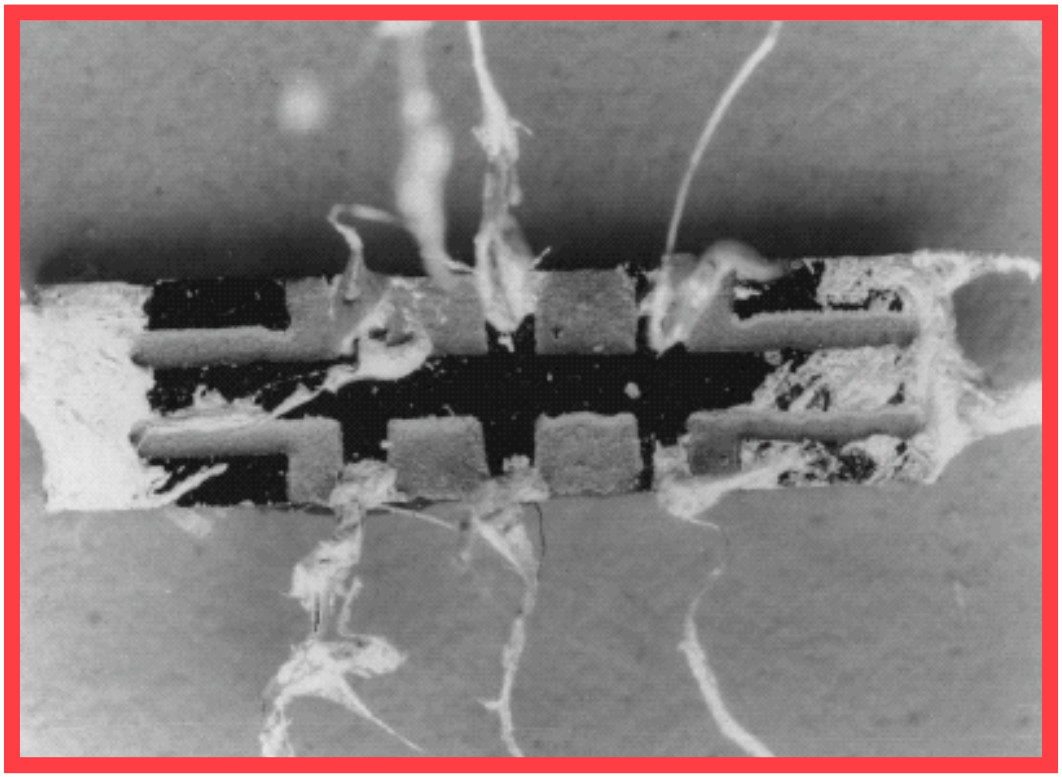
But remember, the first transistor wasn't pretty at all…

"This circuit was actually spoken over and by switching the device in and out a distinct gain in speech level could be heard and see on on the scope presentation with no noticeable [sic] change in quality."
-- Walter Brattain, December 24, lab notebook

G² facts #14: Big discovery appears to be happening near Xmas

1- Cory Dean's quest for the Non-abelions





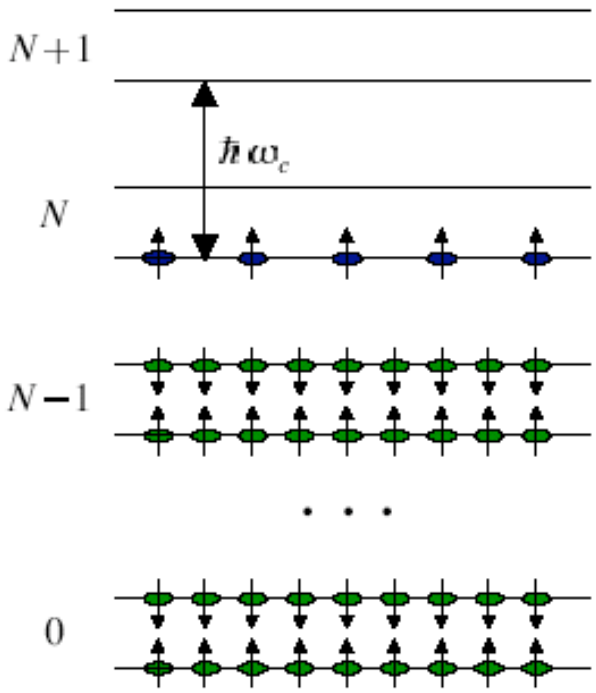
Photograph of the GaAs/AlGaAs sample in which the **Fractional Quantum Hall Effect** (FQHE) was discovered in 1981 by Tsui, Stormer and Gossard. That ugly piece of shit made history.

***G^2 facts #15**: It does not matter how good it looks, it's how good it actually is….*

T=0 sounds fun, how about high-fields B?

2DEG (flatland) in a magnetic field B

$$E_N = (N + 1/2)h\omega_c$$



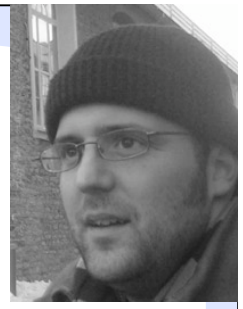
Landau level **Degeneracy** $= \frac{eB}{h} = \frac{B}{\phi}$

(or average flux density)

Filling factor $\nu = \frac{n}{(B/\phi)}$

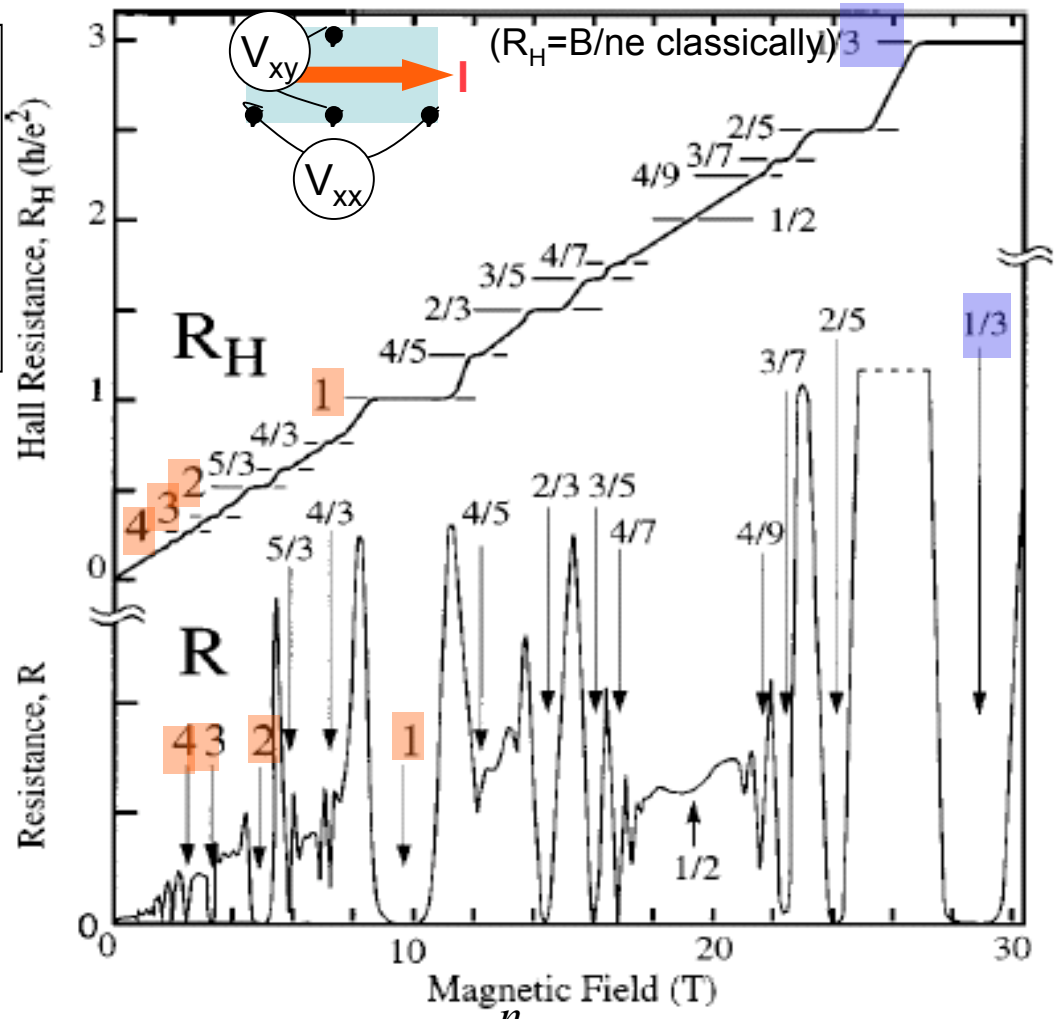
where ϕ=h/e is the flux quantum, and *n* is the electron density

1- Cory Dean's quest for the Non-abelions



$$R_H = \frac{V_{xy}}{I}$$

$$R = \frac{V_{xx}}{I}$$

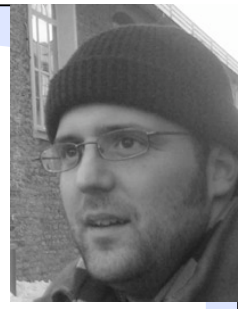


$$R_H = \frac{h}{e^2} \cdot \frac{1}{\nu}$$

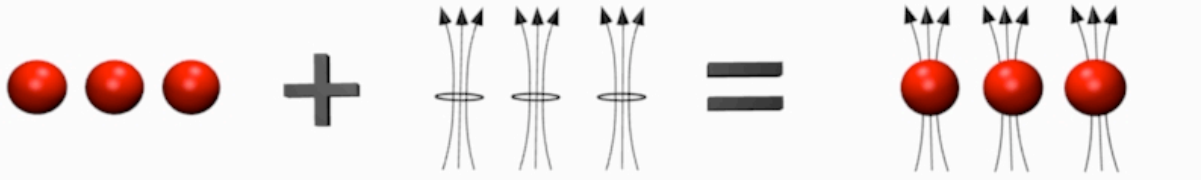
~26 kΩ
at υ= 1

Filling factor $\nu = \frac{n}{(B/\phi)}$ where $\phi = h/e$ is the flux quantum

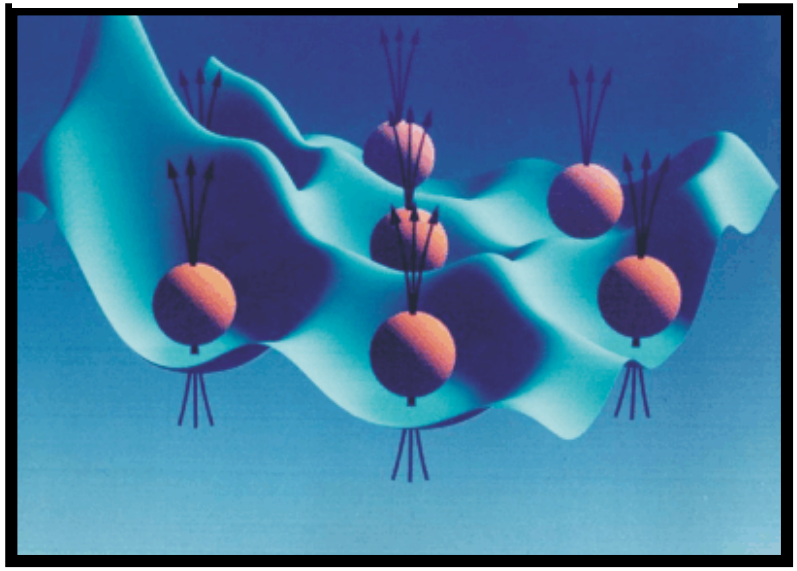
e.g. at ν =1/3 3 times more flux than electrons



1- Cory Dean's quest for the Non-abelions



$$\psi_L = \prod_{i<j} (z_i - z_j)^n \exp\left[-\frac{1}{4\ell^2} \sum_i |z_i|^2 \right]$$



The Laughlin state, at filling factor υ=1/3, as depicted here, also happen to have an excitation electrical charge of ***e*=e/3****. Is that weird?*

G^2 facts #16: These electrons can be real crazy near T=0

2- Guillaume Lambert 's Quantum Nanofluidics

Stringent Definitions:

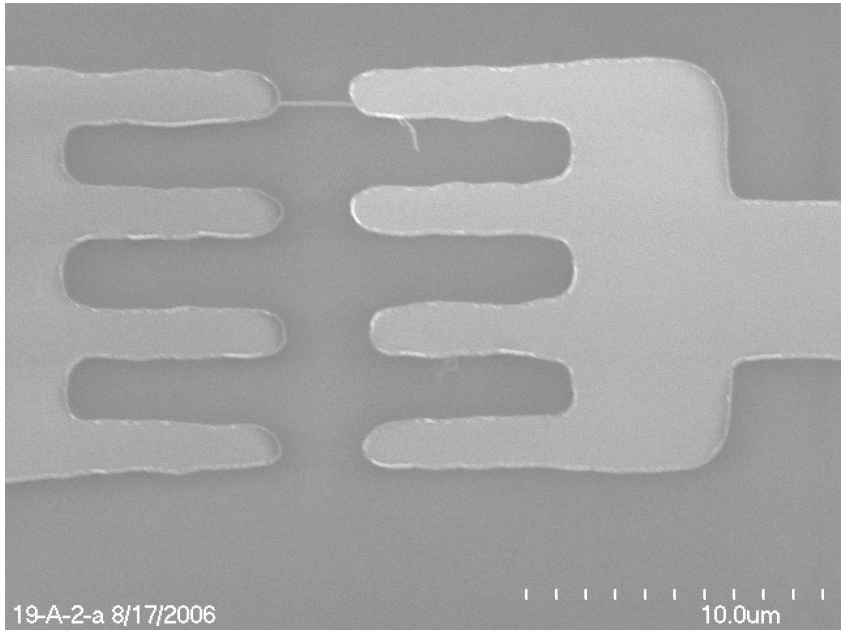
nano:	*darn small (10^{-9} m)*
quantum:	*darn weird to understand*
fluidics:	*darn hard to hold in your hands*

G^2 fact #18: small fluids that will behave according to quantum rules, rather than our boring classical newtonian World, are Cool…

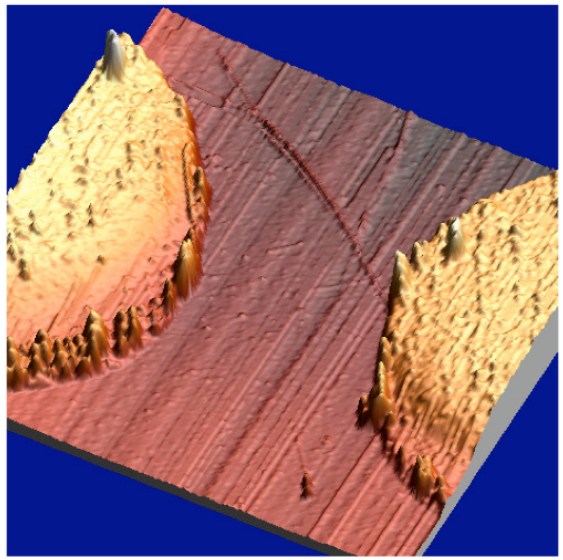
2- Guillaume Lambert 's Quantum Nanofluidics

***G^2 fact #19:** if we can litography our face on a silicon wafer, we can litography just about anything….*

2- Guillaume Lambert's Quantum Nanofluidics

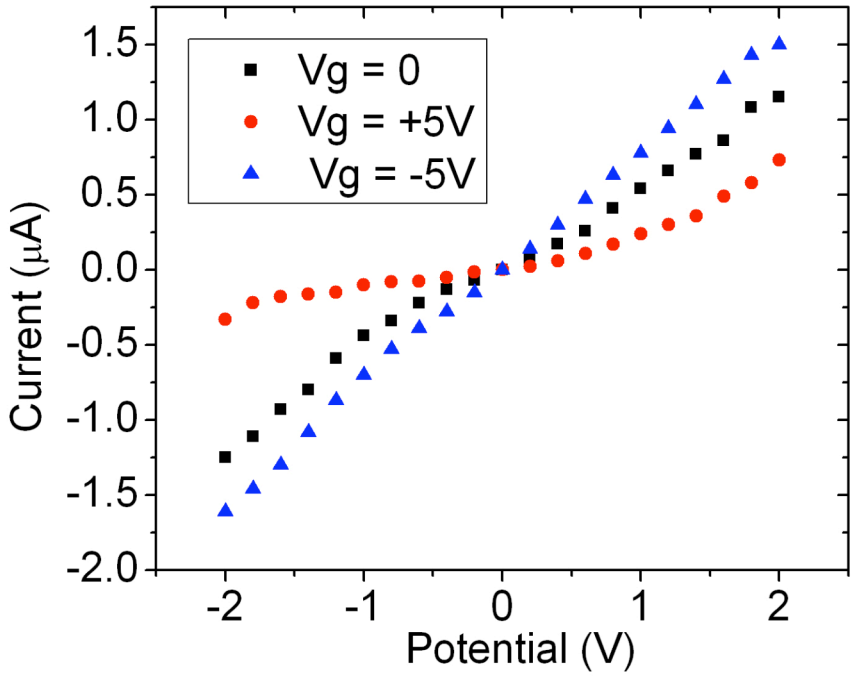


2-C-3-DELTA_TOPO(3.5µm x 3.5µm).TIF :plane



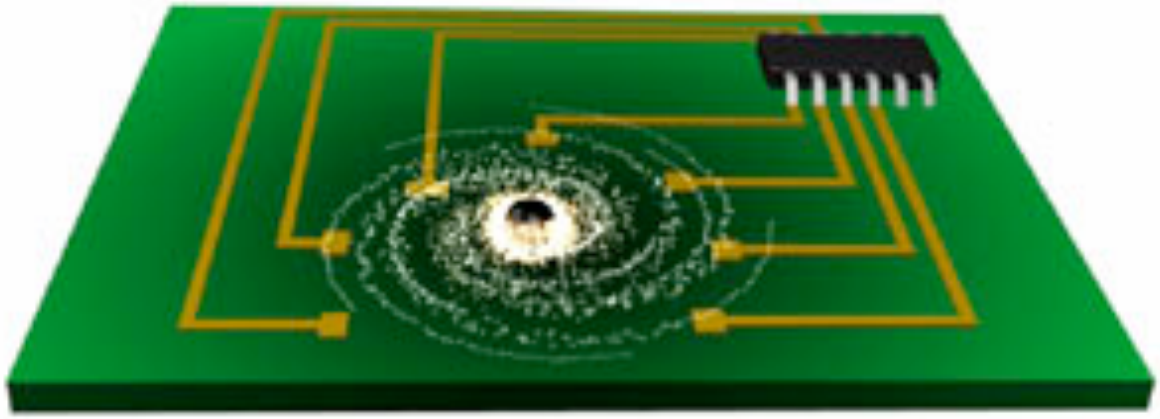
G² fact #20: ***if we can put a carbon nanotube in between two electrical contacts we can flow an electrical current through it….***

2- Guillaume Lambert's Quantum Nanofluidics



G^2 fact #21: *if that little guy is semiconductor, we can make a transistor out-of-it.*

2- Guillaume Lambert's Quantum Nanofluidics

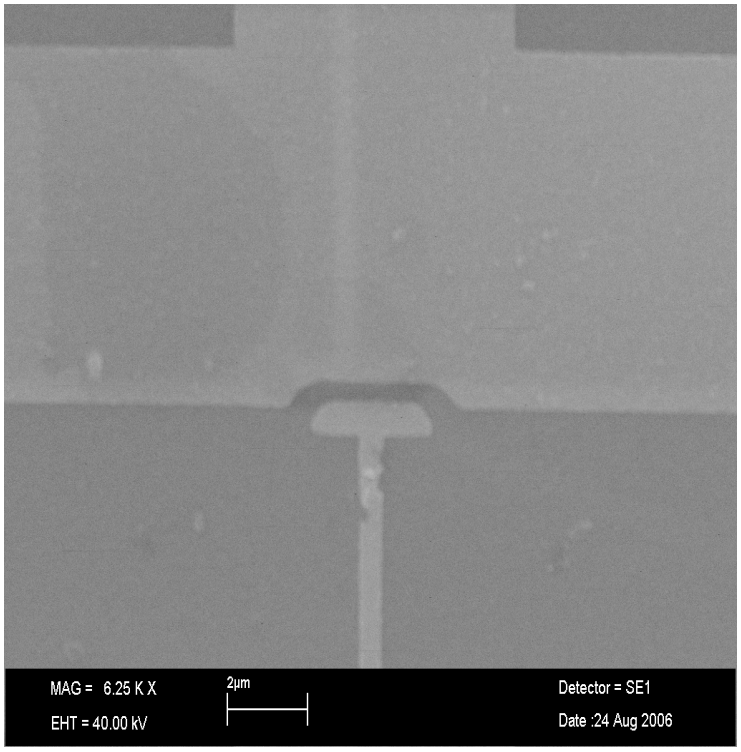


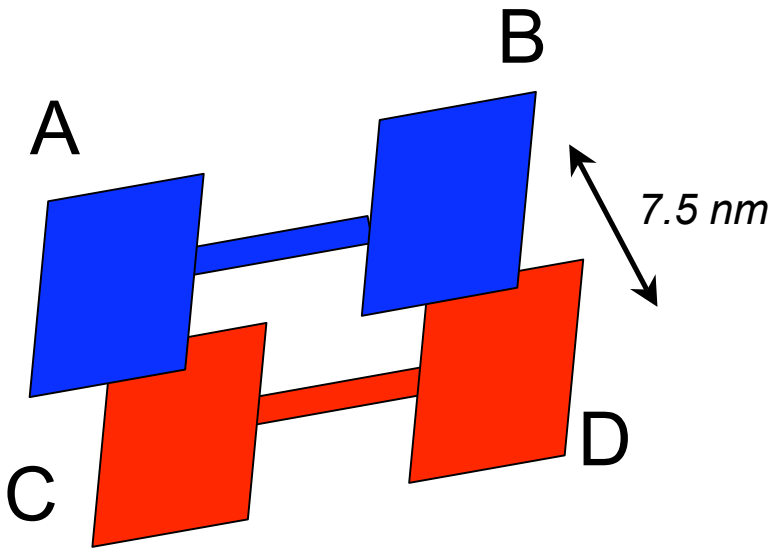
Guillaume Lambert is also trying to create the first "black hole on a chip"

G^2 facts #24: Yeah right.

4- Dominique Laroche's electron drag racing….

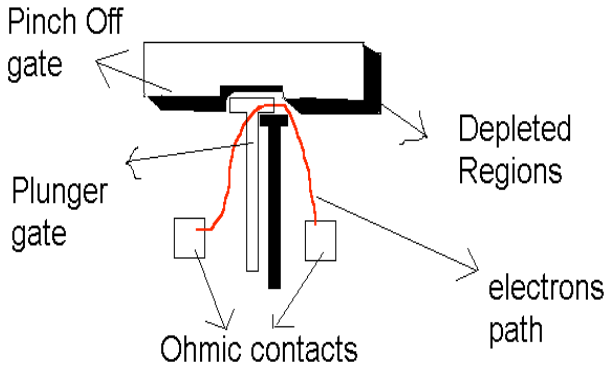
Work in collaboration with Dr. Mike Lilly of Sandia National Labs (USA)

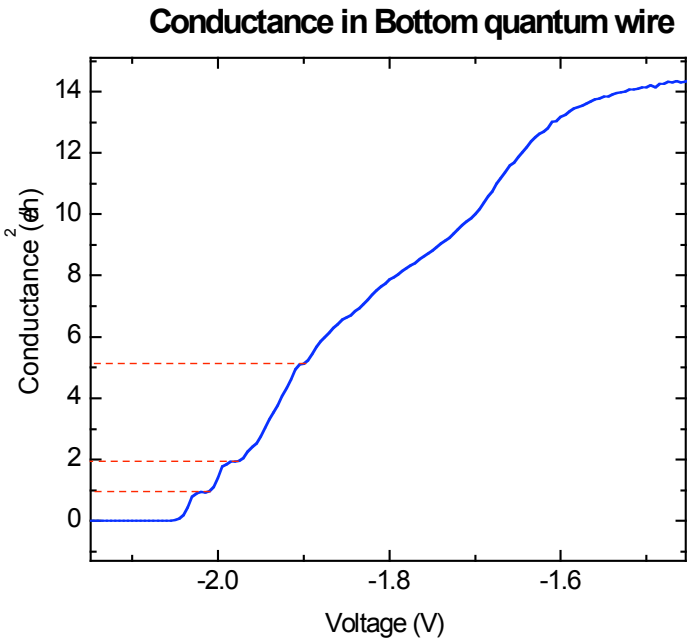


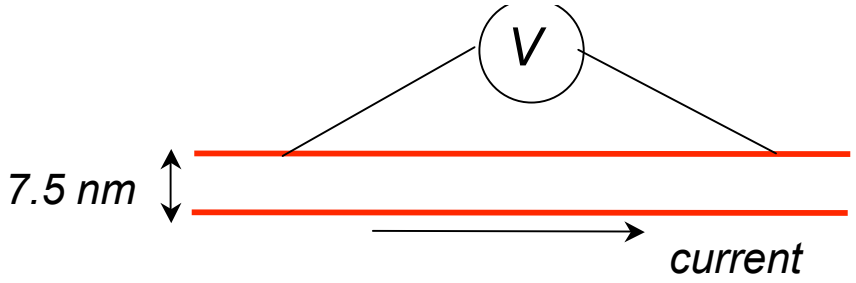


G^2 fact #27: ***If your competitor does not have students as good as those from McGill, then send him one! (and he might even send you some money)***

4- Dominique Laroche electron's drag racing….

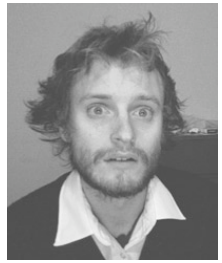




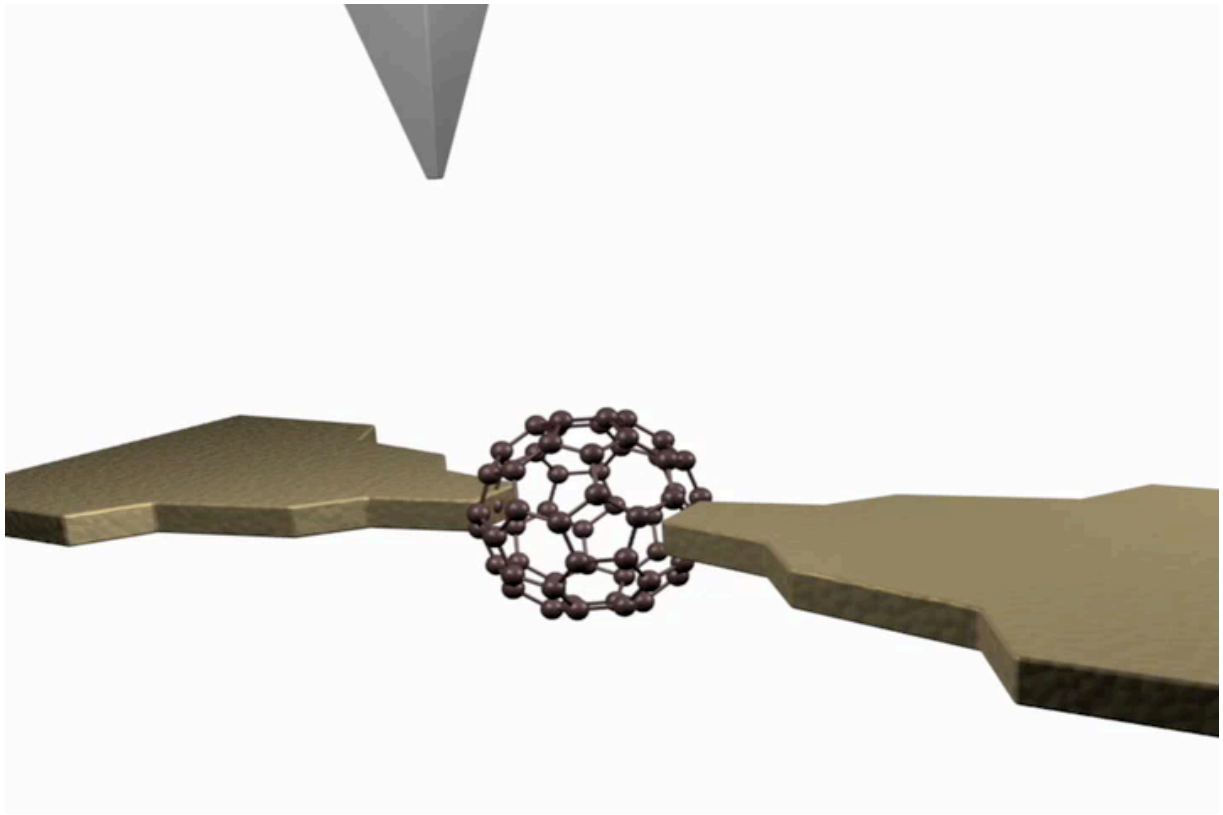


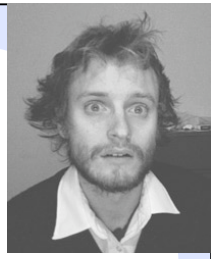
***G² fact #28**: Yip, by 'drag racing' electrons we are hoping to prove/disprove whether these guys are Fermi or Luttinger liquids.*

5- James Hedberg's T=0 microscope



A cool experiment version ***Peter Grutter****:* C_{60} *bucky ball molecular transistor*

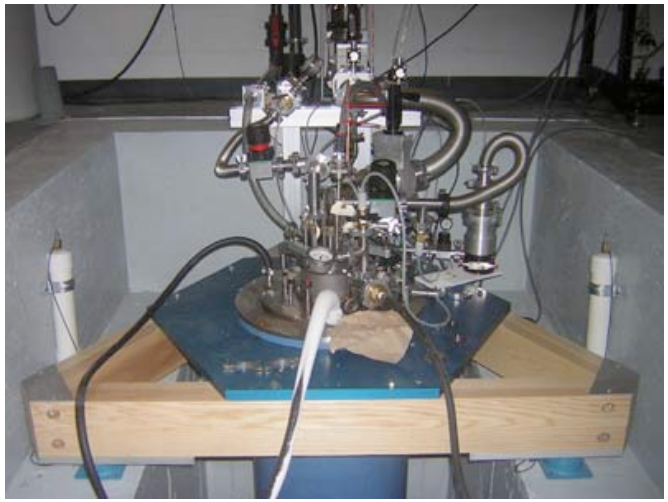




1- James Hedberg's T=0 microscope

Whence the McGill's ultra low-temperature atomic force microscope!

(under construction but as real as wild…)



AFM at 50 mK and 16T

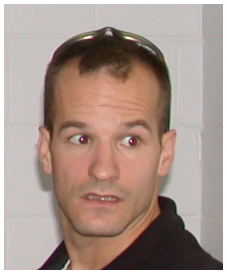
DREAMTEAM ULT-SPM

McGill

Roland Bennewitz

Michael Hilke

Guillaume Gervais



Aashish Clerk

Peter Grütter

G^2 facts #28: Bigger dreams sometimes call for a bigger team…

Last words, and words of wisdom

About the guy who makes noise in the basement:

He hated schools, and schools didn't like him. He preferred motorbikes, mountain bikes, turkish kids, and poetry. He dreamed of oceans, and deserts, but ended up back in Montreal. Go figure!

I guess he still managed to become a physicist, and an old university professor, due to McGill's recent, and unprecedented decrease in hiring standards……

G wisdom #1: why not doing physics like doing extreme sports? Or arts? Or poetry? Passion is key to everything….and the adventures, intellectual or else, must go on….

Last words, and words of wisdom

About that T=0 nano-fluff and nano-stuff I do now for living:

Near T=0, new properties of matter (electronic or else) emerge quantum mechanically from the competing interactions, fluctuations, confinement and disorder. ***The bare quantum systems have already shown us striking, if not totally insane new physics (e.g. e*=e/3) and there may be some more delicacies waiting to be discovered.***

Yeah, this brave 'new' T=0 nano-world isn't just small, it looks as if it could ***even be interesting!***

About Nano-stuff:

C'est pas parce que l'on est p'tit qu'on peut pas etre grand!" - La Guerre des Tuques

About Cold-stuff

It's not because it's darn cold, that it can't be red hot……

The greatest collection of students @ McGill

Cory Dean, Ph.D (Canada/USA)

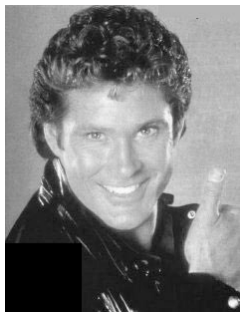
James Hedberg, Ph.D (USA)

Jonathan Buset, M.Sc. (Canada)

Dominique Laroche, M.Sc. (Canada)

Andrew Mack, B.Sc. (USA)

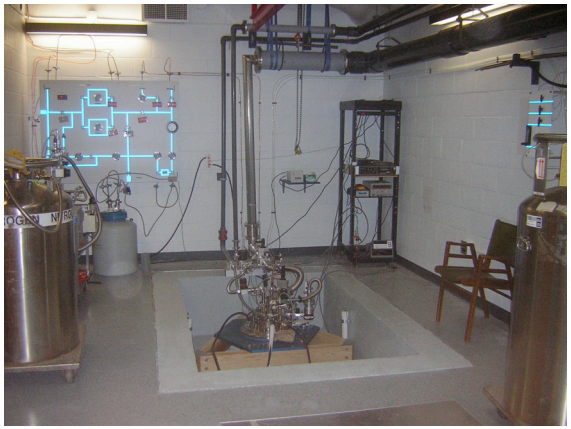
Gregory Crisp, B.Sc. (USA)

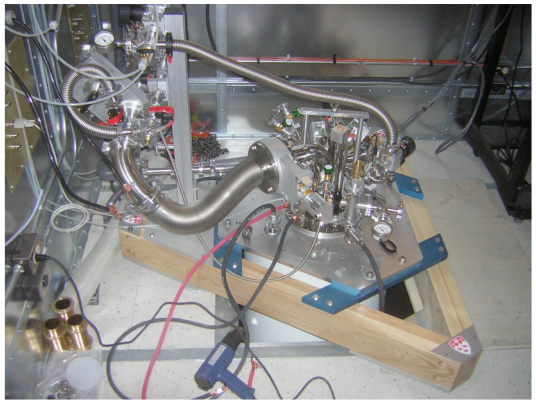


Guillaume Lambert, B.Sc. (Canada)

We thank George W. Bush for supplying us with high-quality students

I would like to thank You All, the best departmental staff I ever work with, and who made it possible to get my lab going fast, and make my life much easier every day.





NSERC CRSNG

Fonds de recherche sur la nature et les technologies Québec

McGill

CIAR

ALFRED P. SLOAN FOUNDATION

Canada Foundation for Innovation
Fondation canadienne pour l'innovation