

Shot Noise in Tunneling Junctions

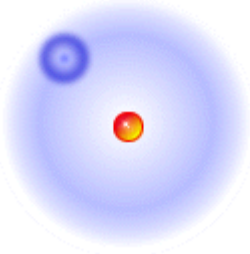
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8/6/08

A simple explanation of electron tunneling

With lots of pictures and no equations

1 atom

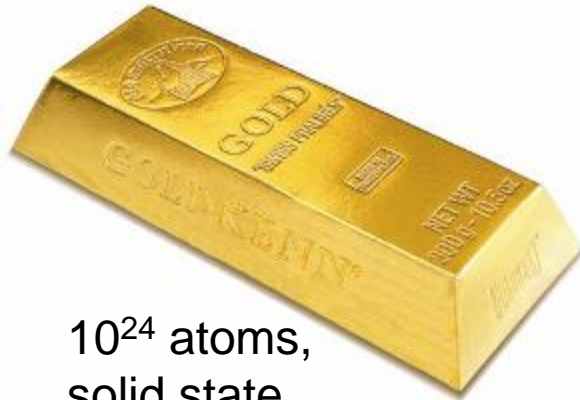


$n = \infty$	-----	$E = 0$
$n = 4$	=====	$E = -0.85 \text{ eV}$
$n = 3$	=====	$E = -1.51 \text{ eV}$
$n = 2$	=====	$E = -3.40 \text{ eV}$

Discrete levels

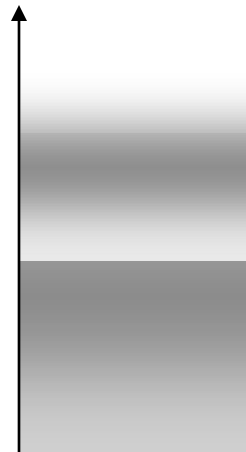


$n = 1$	=====	$E = -13.6 \text{ eV}$
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10^{24} atoms,
solid state

Energy (ϵ)



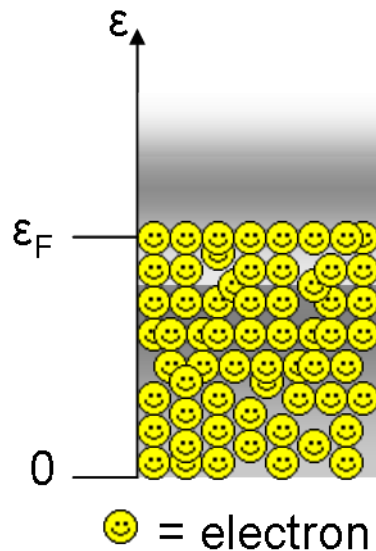
Electronic bands

Pauli exclusion principle: electrons are unfriendly

Electrons not allowed to occupy identical states

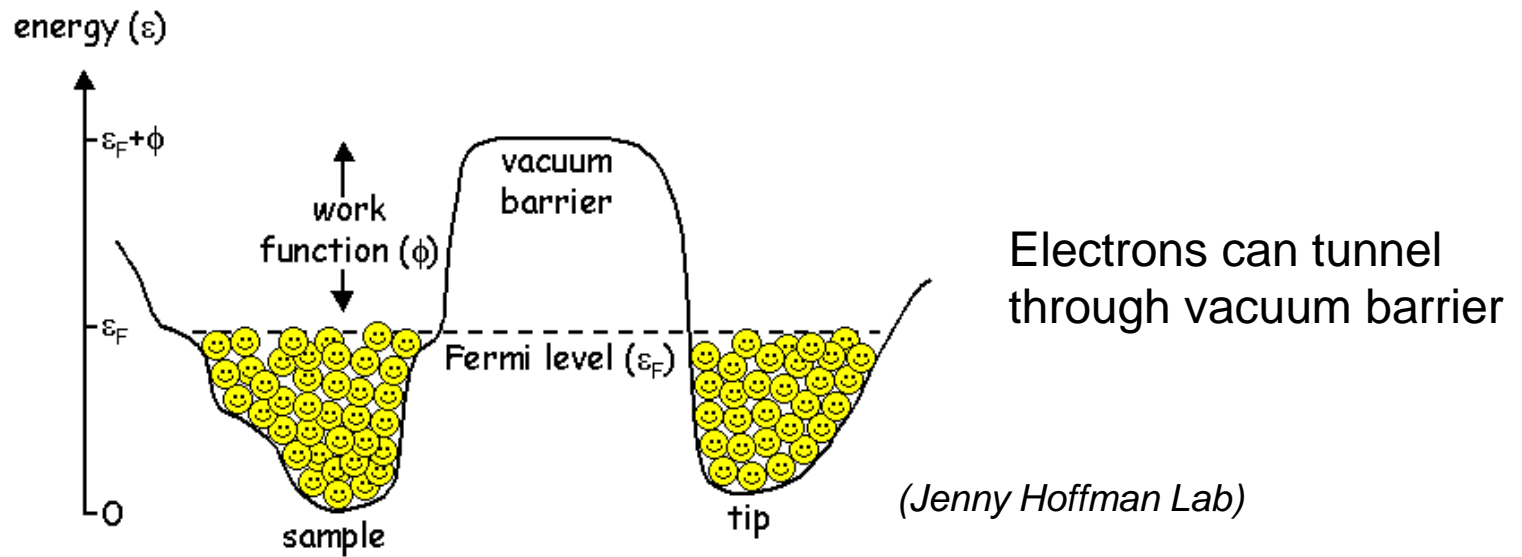
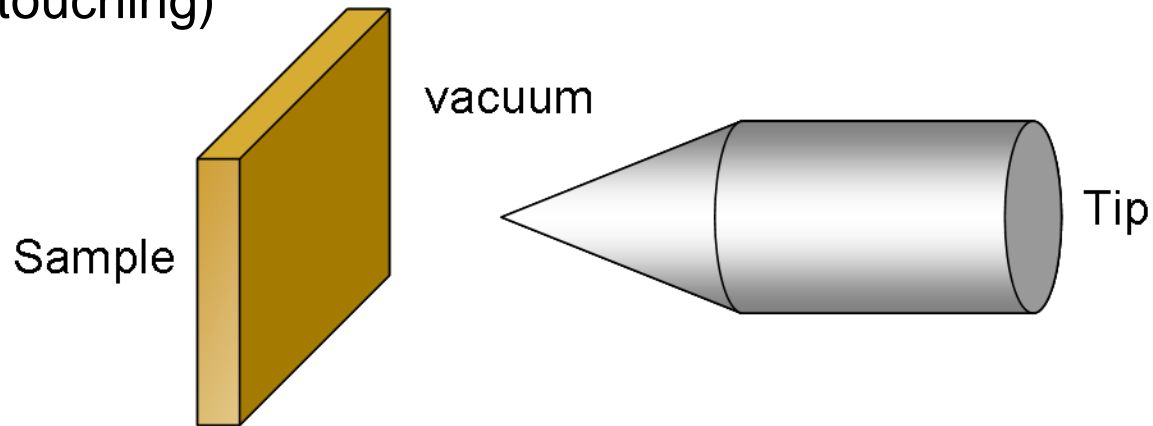
Electrons pile on top of each other to fill up energy states

Until you run out of electrons at ε_F



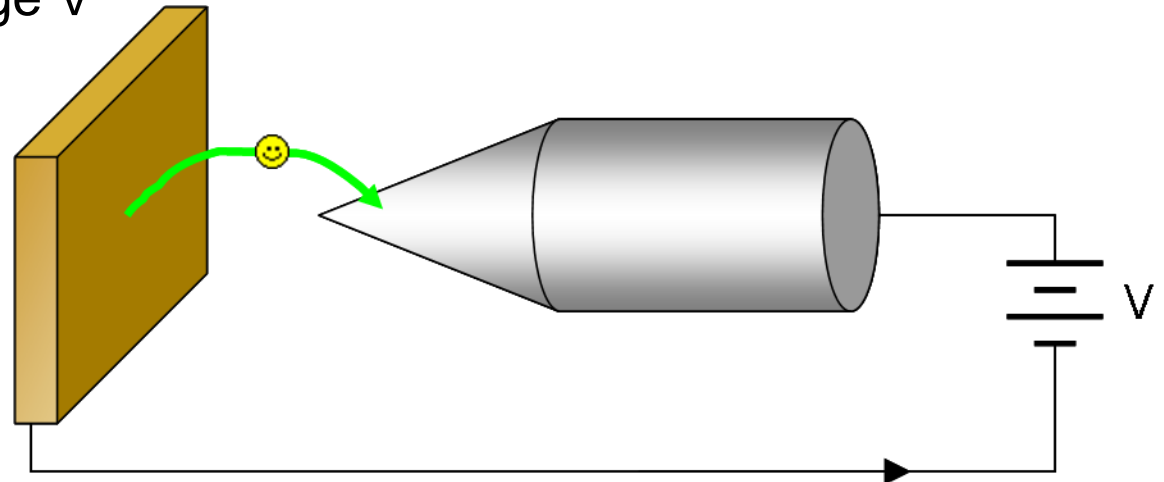
Fermi energy ε_F = top energy level
at which electrons sit

Take two pieces of metal and bring them extremely close
(but not touching)



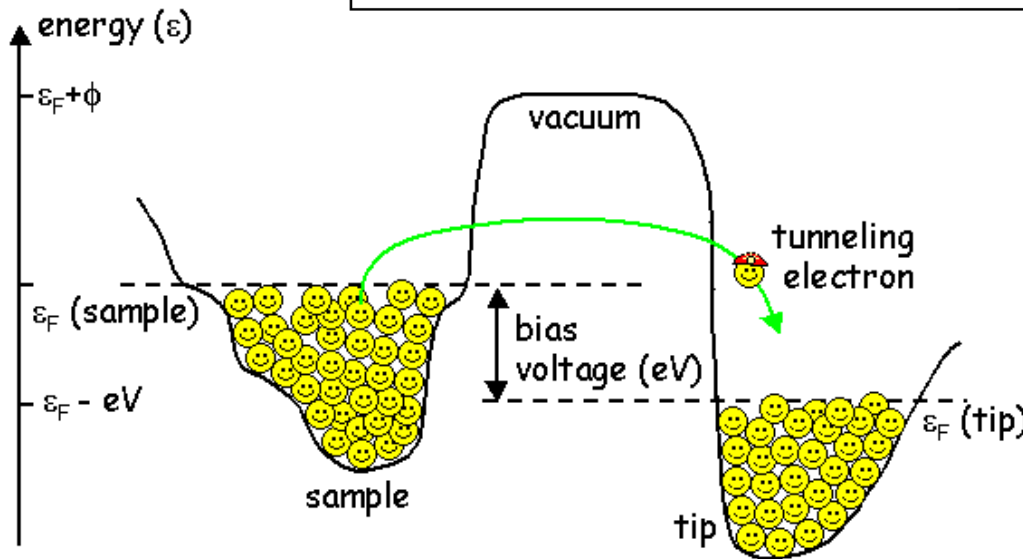
For tunneling, electrons need empty states to tunnel into

Apply bias voltage V



Tunneling current increases with V

$$V = I R$$



A simple explanation of electronic shot noise

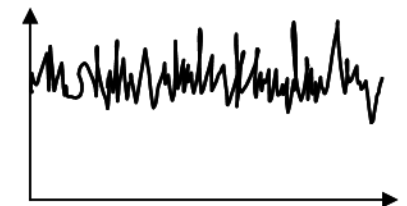
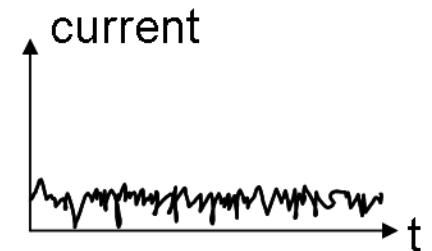
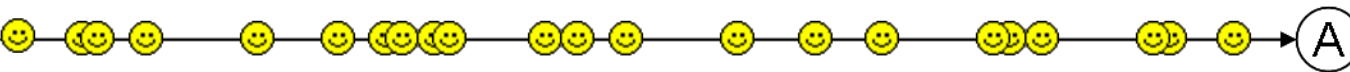
Electrons have discrete charge

Any current of electrons has small random fluctuations called shot noise

Shot noise is white (flat frequency distribution) and Gaussian

Shot noise increases with current: $i_n = \sqrt{2eIB}$

Only becomes significant for very small currents

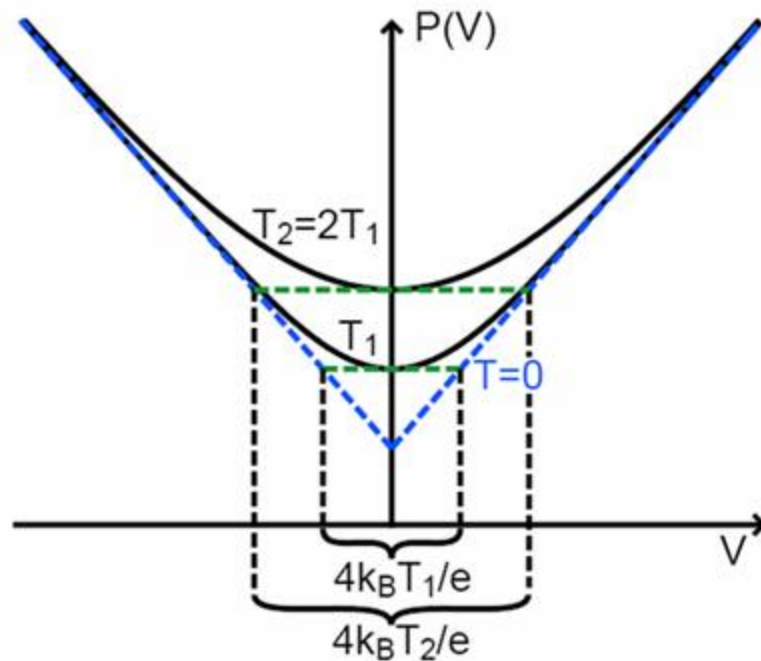


Tunneling current is usually very very small: $\sim 10^{-9}$ A

So shot noise becomes significant in tunneling junctions

Shot noise does not go to zero (except at absolute zero)

Thermal (Johnson) noise always present



$$P \propto i_n^2 \propto V \coth\left(\frac{eV}{2k_B T}\right)$$

(Lafe Spietz)

So what's this experiment all about?

Goal: develop high-frequency, low-noise instrumentation to measure the shot noise in a tunneling junction

Why high-frequency? Remember $i_n = \sqrt{2eIB}$

So more bandwidth means a better measurement

Eventually we want to implement this on a scanning tunneling microscope (STM)



Shot noise STM

What happens if a group of particles behaves like a single quasiparticle?

This happens in certain materials at certain conditions

Can have charge $2e$, $e/3$, $e/5$, $e/7$, etc.

Shot noise becomes $i_n = \sqrt{2qIB}$

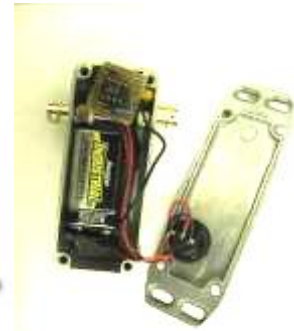
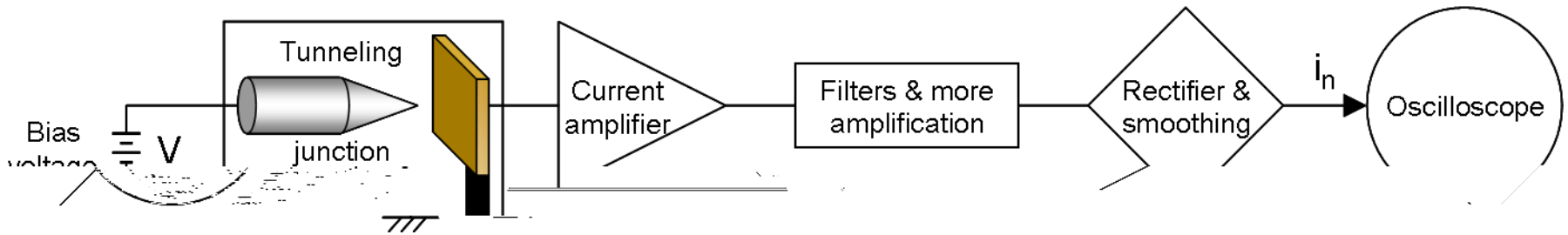
Curve changes in measurable way



So with shot noise STM we can find quasiparticles

Map out their locations

Experimental apparatus

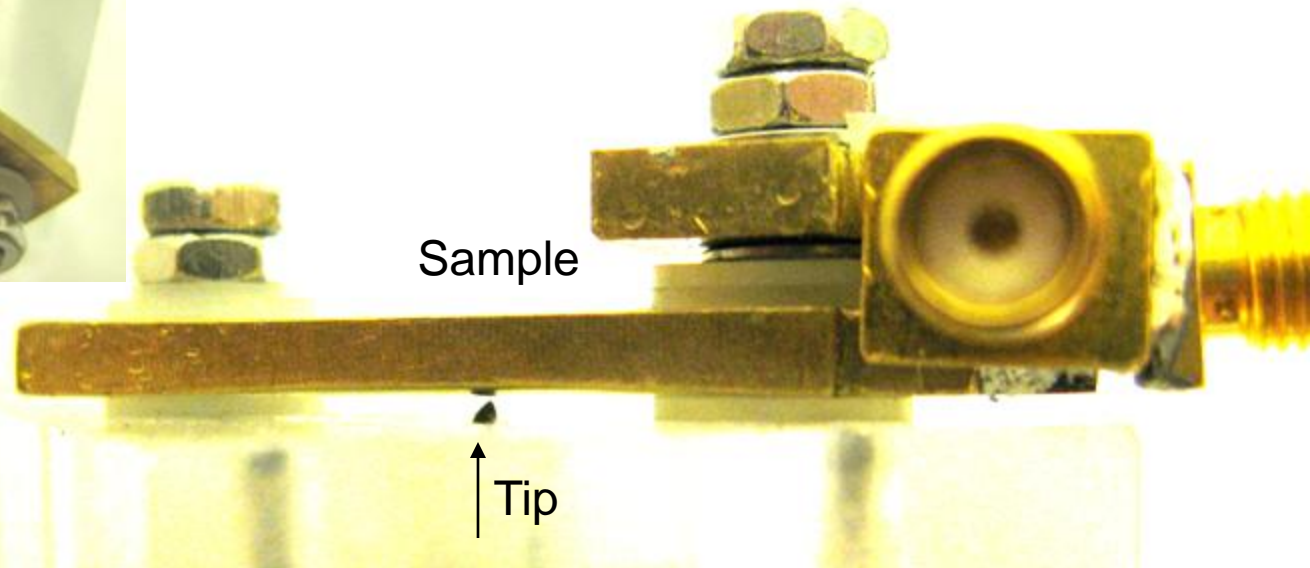
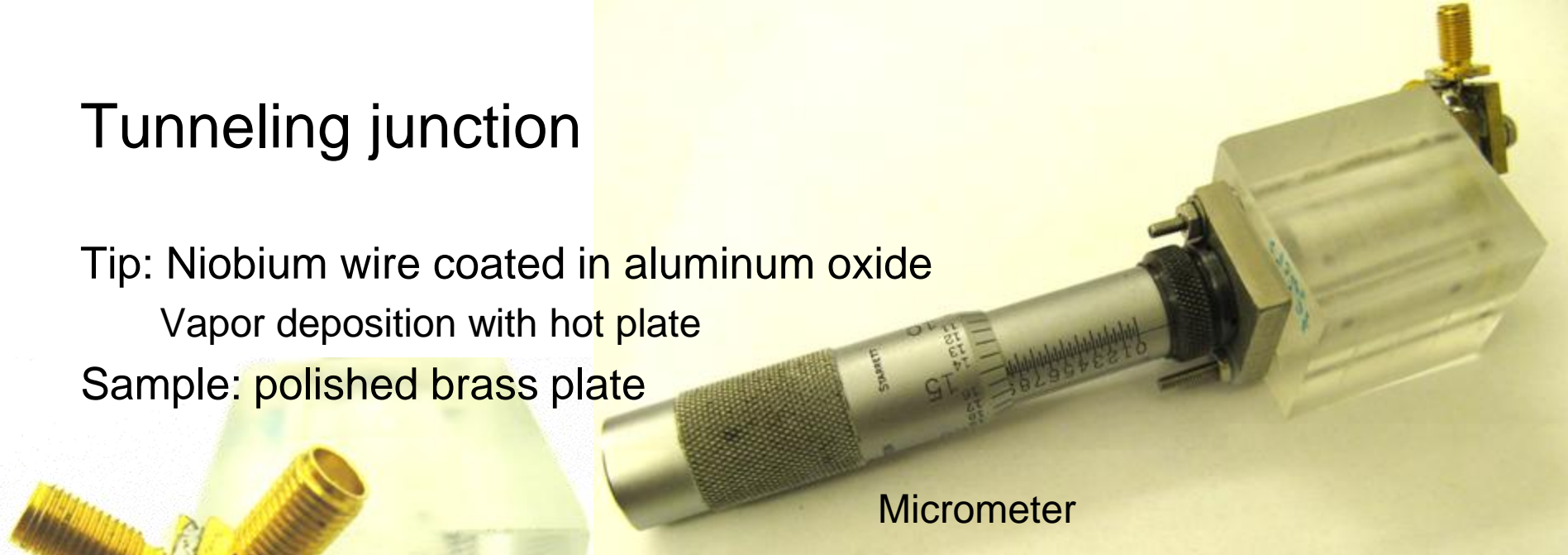


Tunneling junction

Tip: Niobium wire coated in aluminum oxide

Vapor deposition with hot plate

Sample: polished brass plate



Current amplifier

3 dB bandwidth: 4.2 MHz

I-to-V gain: 50 k Ω

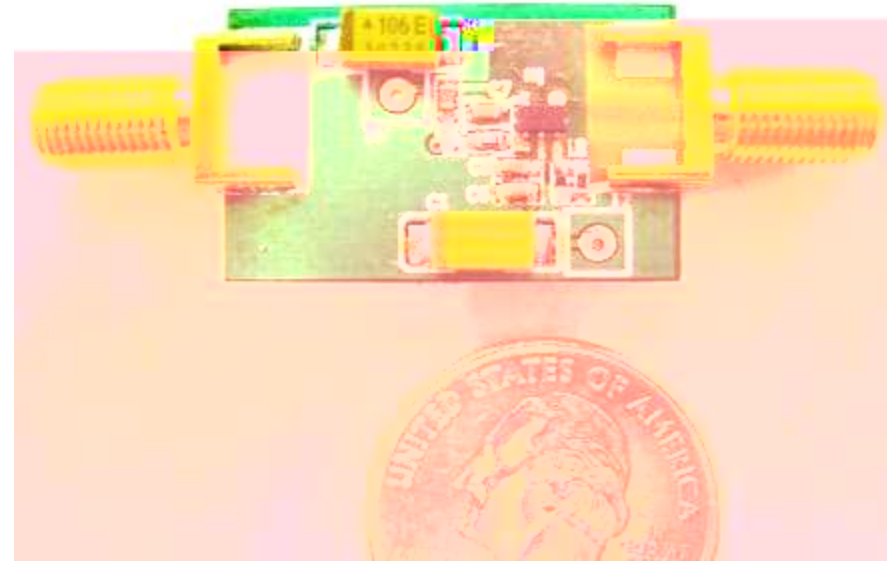
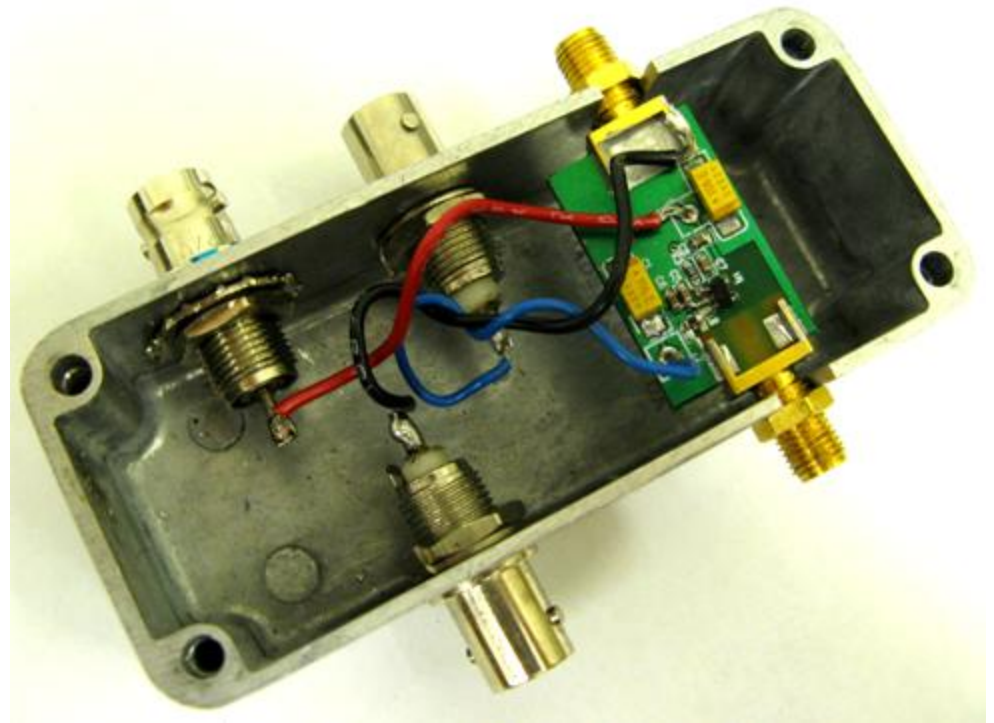
Uses AD8067 FET op-amp

High gain-bandwidth product

High speed

Low noise

Total RMS output voltage noise
through 150kHz: 34.5 μ V



Filters and preamp

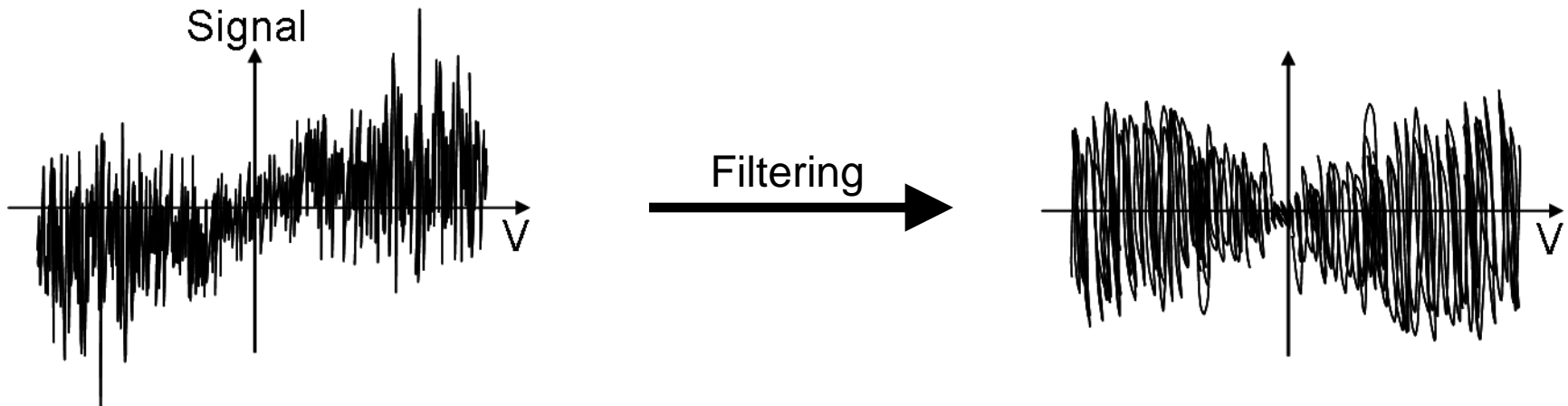


SR560 preamp

V-to-V gain: 10^4

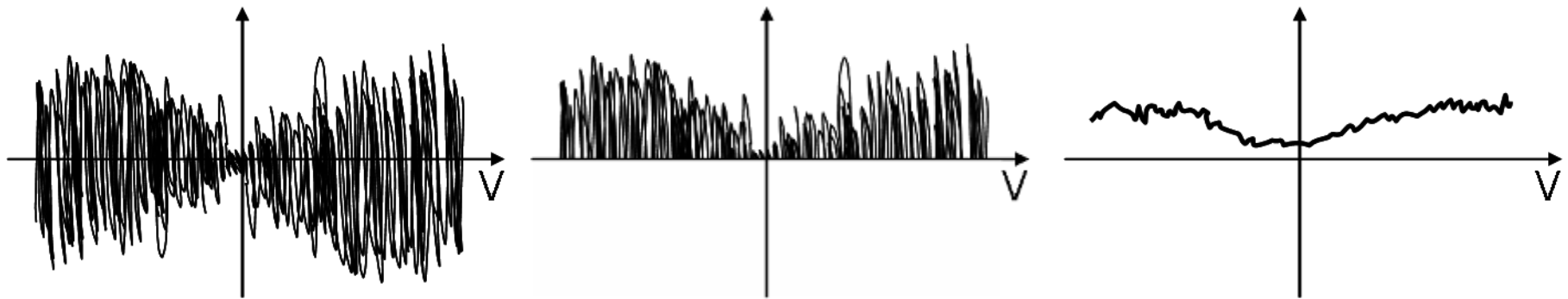
10 kHz high-pass, 100 kHz low-pass (first order)

Effective bandwidth: 143 kHz



Rectifier & Smoothing

Automatically measures noise amplitude



Signal from
preamp

Rectifier

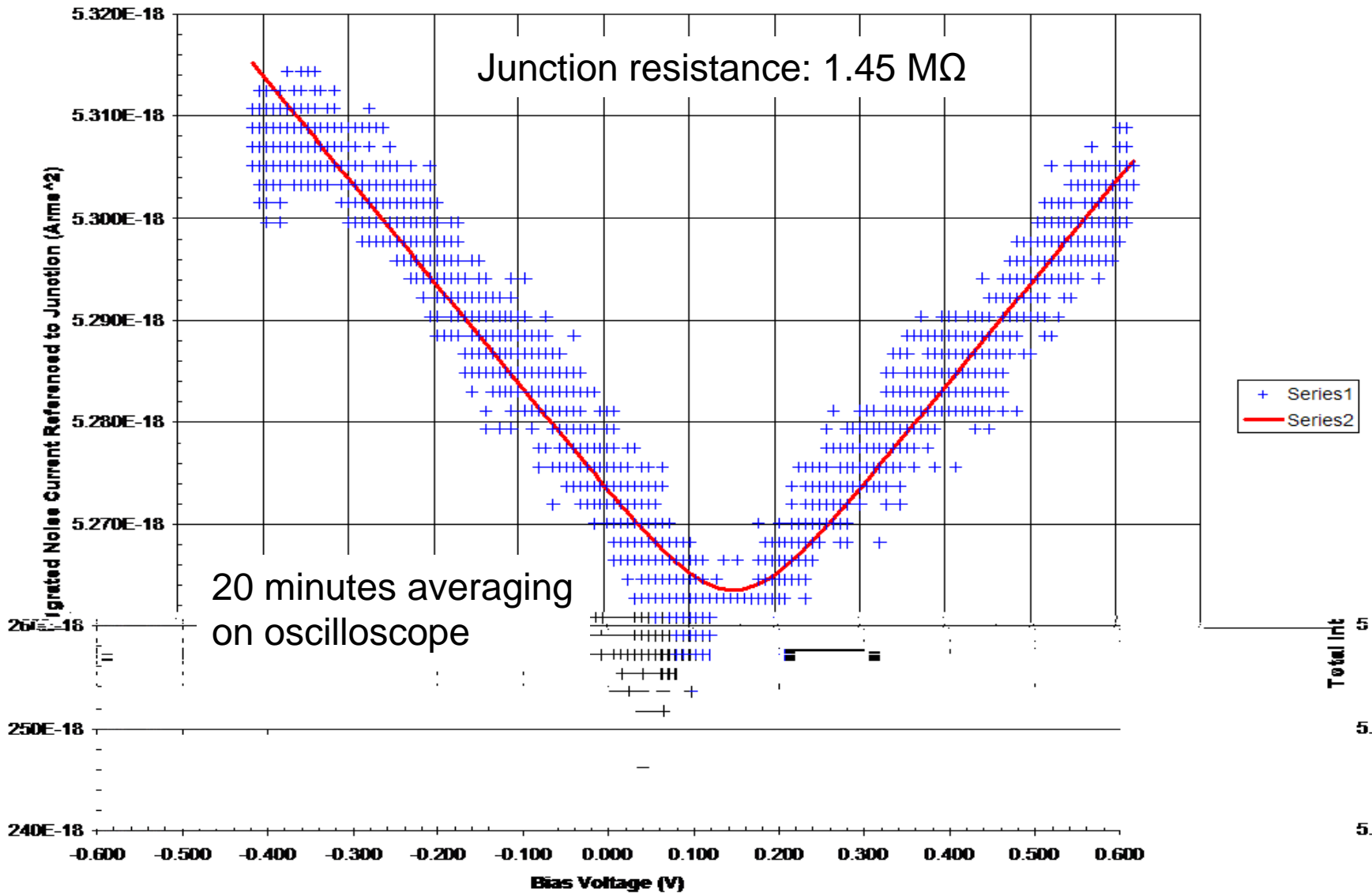
1/2 signal

Smoothing

Smoothed
1/2 signal

Smoothed 1/2 signal is directly proportional to RMS noise amplitude

Can now fit this data to $V \coth\left(\frac{eV}{2k_B T}\right)$

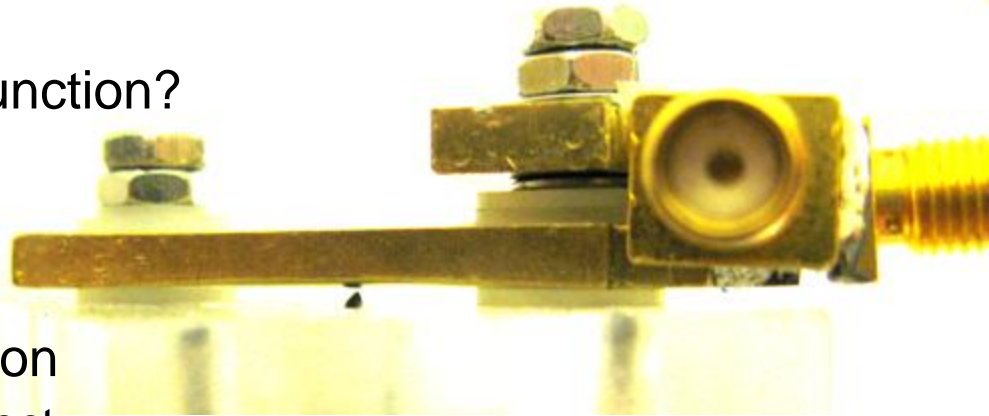


Conclusion

Measure shot noise on tunneling junction?

Probably – data looks pretty good

Need better data to be sure



Biggest weakness: tunneling junction

Nonlinear tunneling resistance effect

Resistance changing slowly and unpredictably

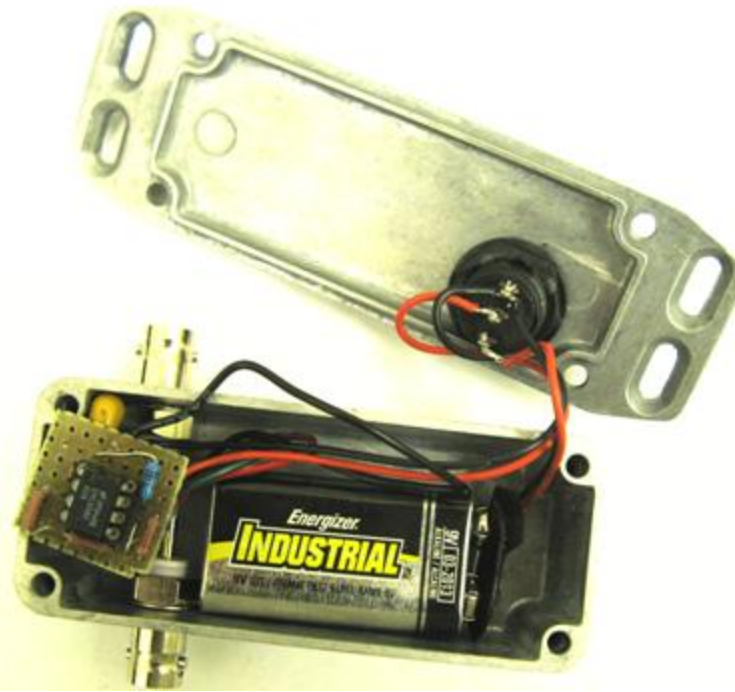
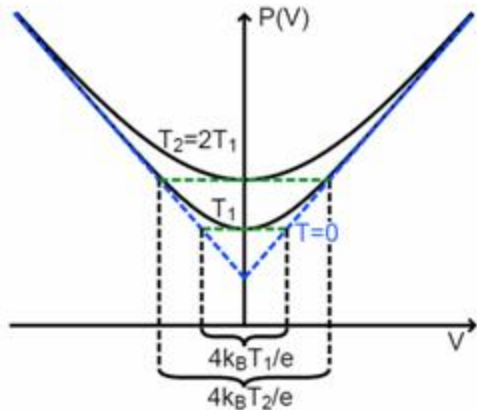
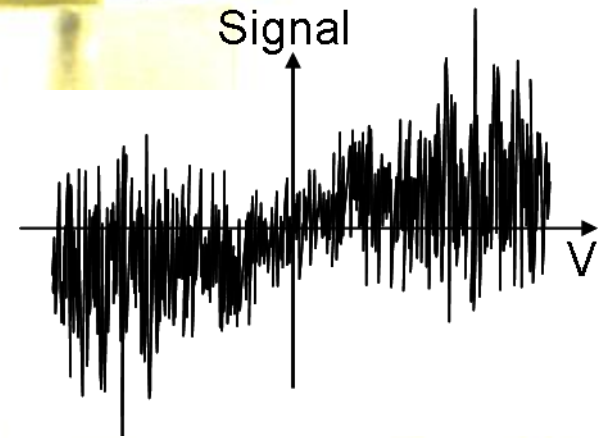
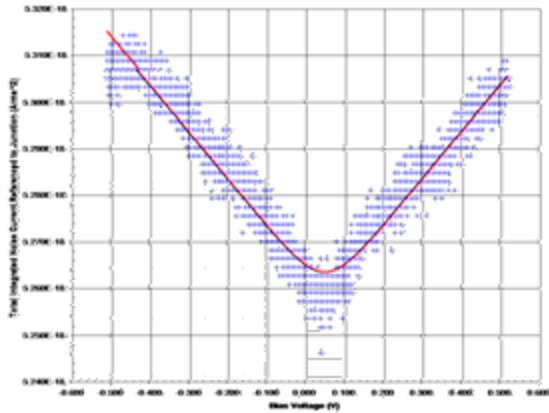
Even if data is bogus, this experiment shows that I have enough resolution to detect shot noise on tunneling junctions.

Instrumentation

Should be easy to install on STM

Custom-built electronics are robust

Questions?



$$P \propto i_n^2 \propto V \coth\left(\frac{eV}{2k_B T}\right)$$