Building a High Precision Calorimeter to Investigate the Condensed Matter Casimir Effect

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Motivation and Questions:

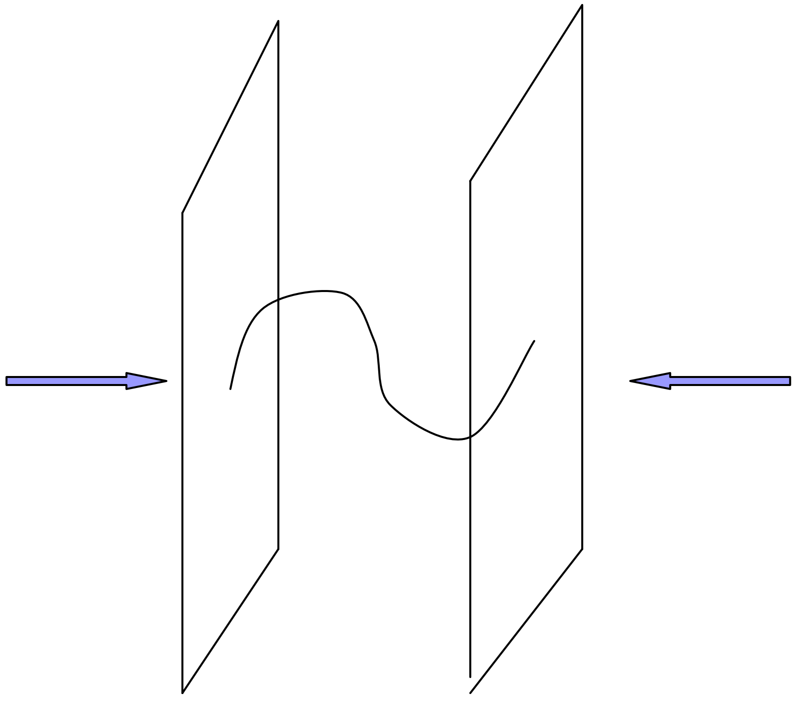
- We are building a calorimeter…Why?

  Answer: We want to look at the **condensed matter Casimir Effect.**
- How do we build it?
- What are our considerations while building?

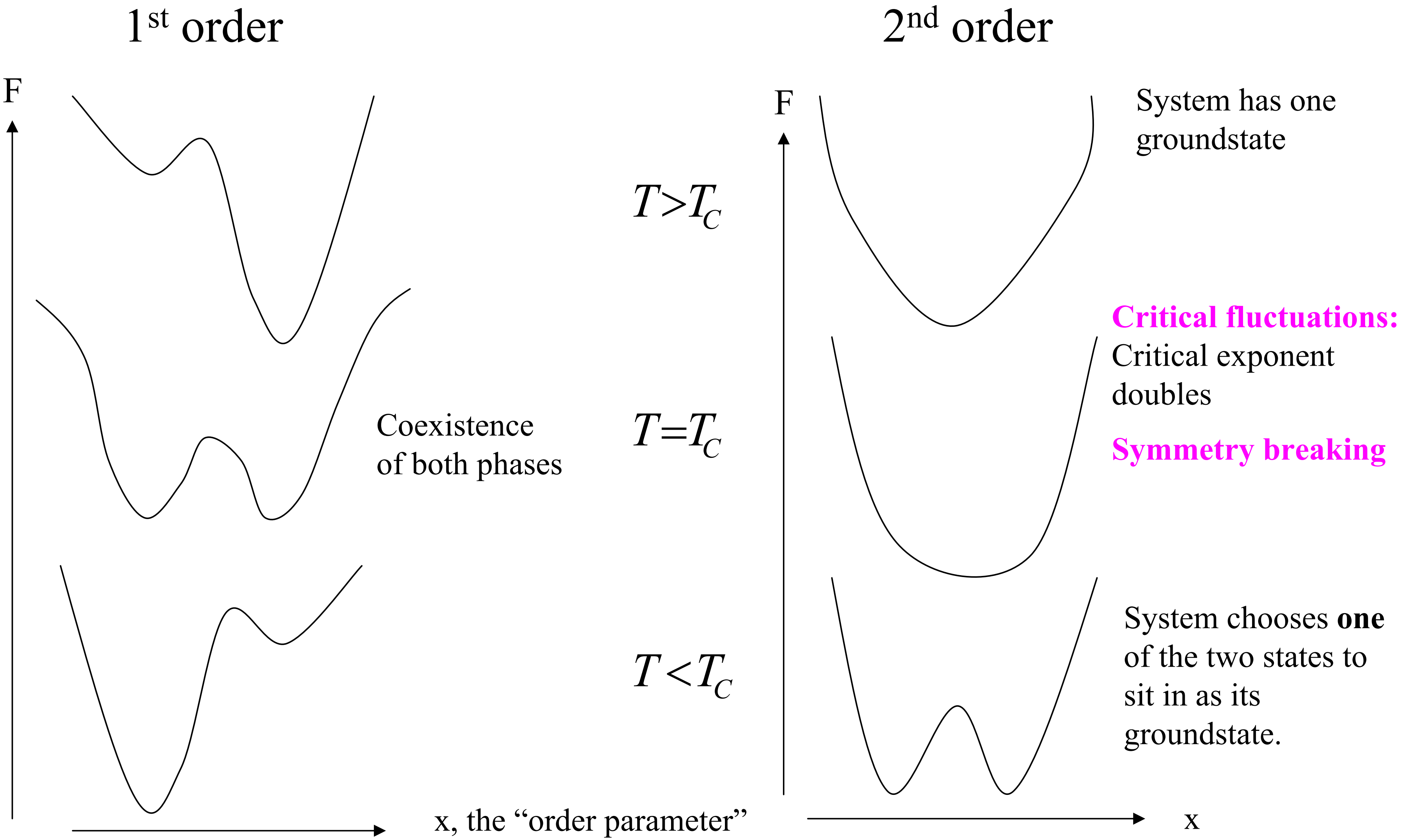
  Answer: precise temperature control and measurement, uniform radiative environment.
- Uses/macroscopic cases of the CM Casimir Effect and future work.

Prelude: The Electromagnetic Casimir Effect

- **Uncharged, conducting** plates in vacuum box, **a few hundred nm apart.**
- Vacuum has “virtual” EM particles with modes of vibrations, which are called **zero point fluctuations.**
- Only modes of small wavelength fit between the plates, while both small and large wavelengths fit outside the plates.
- So: get net **small attractive force** between the plates.



Interlude: Critical Fluctuations from the Second Order Phase Transition



$T>T_C$

System has one groundstate

$T=T_C$

Coexistence of both phases

Critical fluctuations: Critical exponent doubles

Symmetry breaking

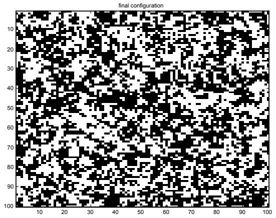
$T<T_C$

System chooses **one** of the two states to sit in as its groundstate.

x, the “order parameter”

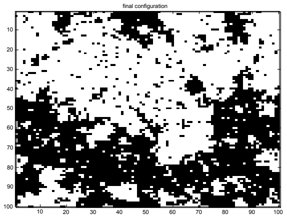
Critical Fluctuations

- Since the bottom of the curve at T=Tc is flat, we have many x with the same free energy F.
- System has **no definite preferred x**, so we have fluctuations between many values of the order parameter.
- Critical liquid looks like macroscopic “chunks” of phase A and phase B.
- **Example**: **ferromagnet**: A=areas of spin up, B=areas of spin down, x=M.



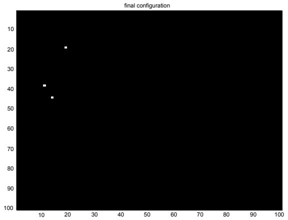
$T > T_C$

Equilibrium state: M=0



$T = T_C$

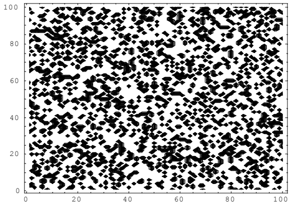
Symmetry breaking



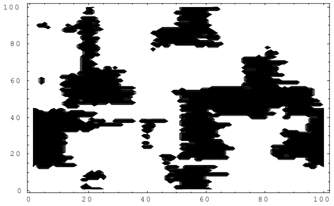
$T < T_C$

$M = M_0$

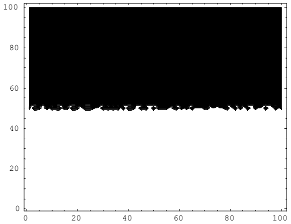
- **Example**: **critical liquid**, difference with ferromagnet is that phase A and B are conserved
- Transition known as an **immiscibility transition,** x may be the fractional composition of water.



$T > T_C$

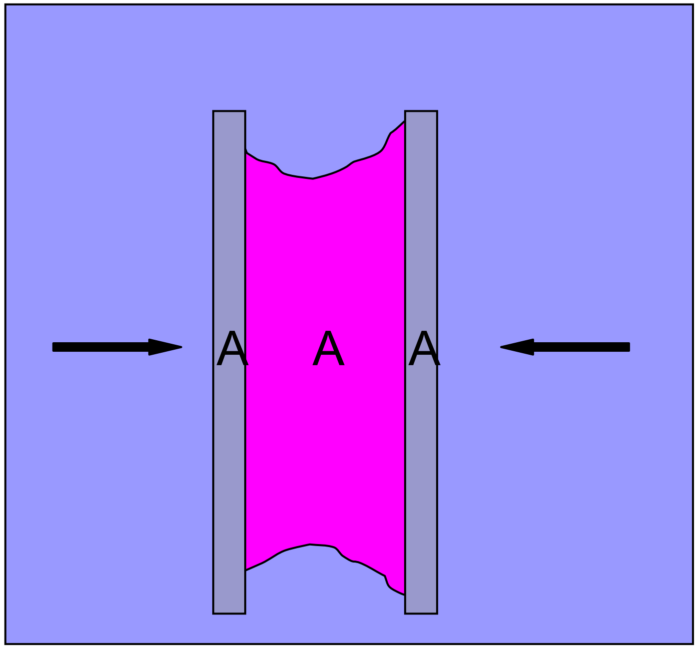


$T = T_C$

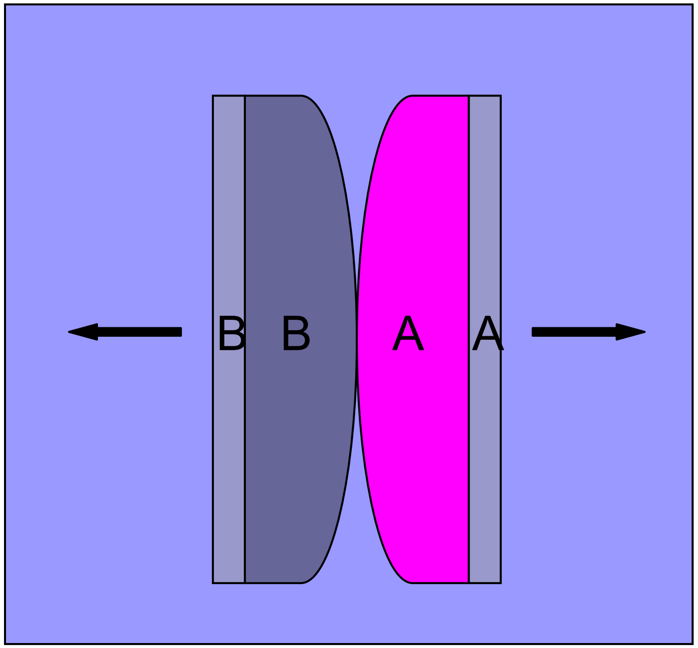


$T < T_C$

The Condensed Matter Casimir Effect



attraction

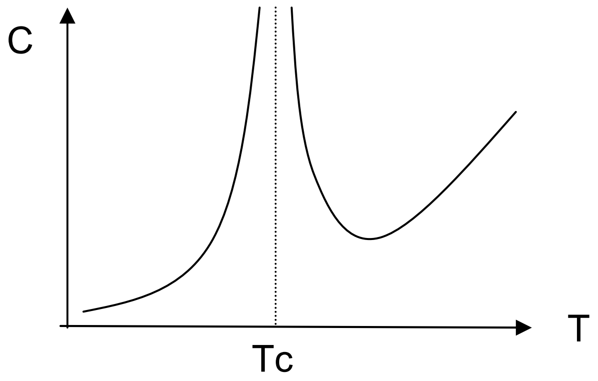


repulsion

- CM Casimir Effect is **macroscopic,** greater than the Van der Waals force at some critical points, and has a **coherence length of ~ 100nm for some critical liquids.**
- **Is an entropic force. F=U-TS.** Smaller S between the plates than outside the plates, so get repulsion between plates in an attempt make entropy uniform.
- Beaker of a **two-phase liquid** (phase A and phase B) undergoing **critical fluctuations.**
- **Two plates** suspended in the beaker.
- **Wetting characteristics** of plates cause either repulsion or attraction between plates **if** we have large enough "chunks" of A and B to wet the plates.

Why a Calorimeter?

- **Goal**: study entropic fluctuation (critical fluctuation) mediated forces, e.g the CM Casimir Effect.
- **But**: how do we ***know*** when we have critical fluctuations?
- **Answer**: solution looks opaque – can find out by making optical measurements using lasers… difficult.
- **Answer 2**: the heat capacity C diverges at a phase transition, so we can measure C, but need high precision, since graph is very steep near Tc.



$$C \propto |T - T_C|^{-\alpha}$$

C diverges at Tc

α doubles at Tc if Tc is a “double critical point”

- Will use a **DC scanning calorimeter** to scan through temperature and look for the divergence in heat capacity.

So:

- CM Casimir Effect is **macroscopic**, comes from fluctuations of liquids near their **immiscibility phase transition.**
- Given a particular wetting characteristic of the plates, say A-A, in a beaker with macroscopic “chunks” of A, we should be able to see some attractive (or repulsive) force between the plates.
- That is, if we know exactly at which T to look.
- Must scan carefully through temperature to look for the divergence in C.
- $\Longrightarrow$ **high precision temperature control and measurement via a calorimeter.**

Building Considerations

- Thermal conductance between various parts of the apparatus.
- Machining small parts such as:
- Bringing wires into and out of the calorimeter.
- Anchoring: wires, pins, epoxy.
- Vacuum compatibility of all components.
- **Must know the temperatures at different locations on the calorimeter at all times and be able to change them according to our desires.**

Temperature Control: Apparatus

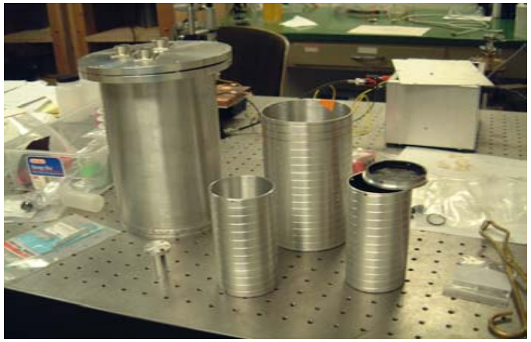
- Sample located inside **double aluminum cans in vacuum chamber.**

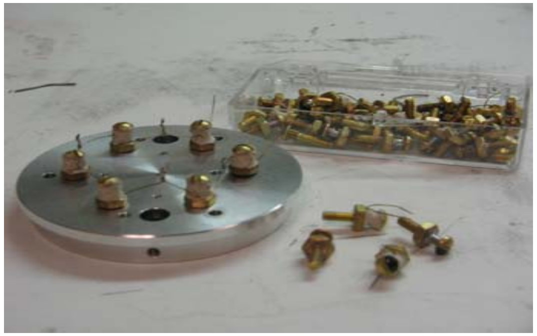
- Power supply, heater wires, **heater spools.**

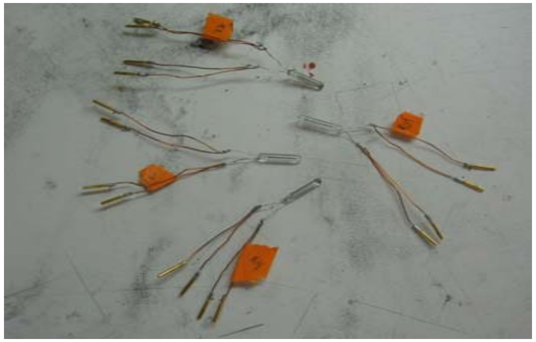
- 5 **thermometers** (i.e. 5 resisters)

- Thermometer calibration.

- The PID algorithm







PID Algorithm: Feedback Temperature Control Loop:

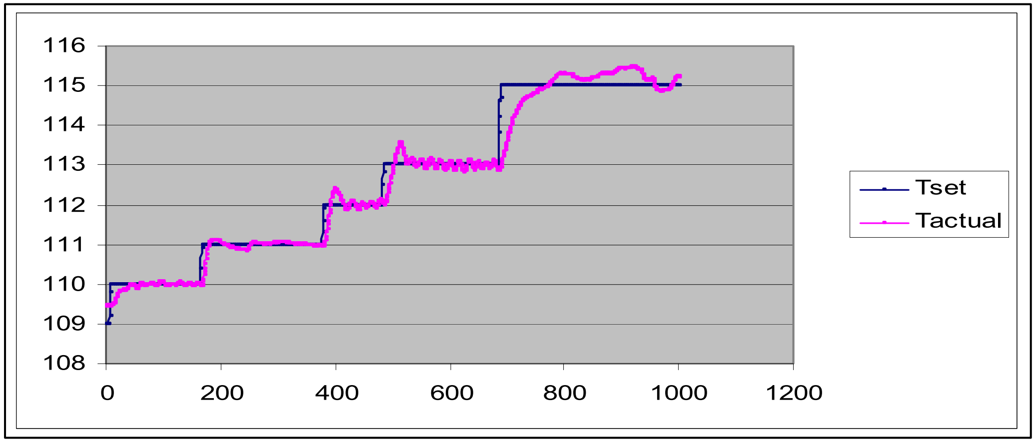
- Controls temperature with 3 terms: **Proportional, Integral, Derivative.**

$$number = k_c[e(t) + k_i \int_0^t e(t')dt' + k_D \frac{d}{dt} e(t)]$$

$$\text{where } e(t) = T_{actual}(t) - T_{set}(t)$$

$$k_c, k_i, k_D \text{ all adjustable constants}$$

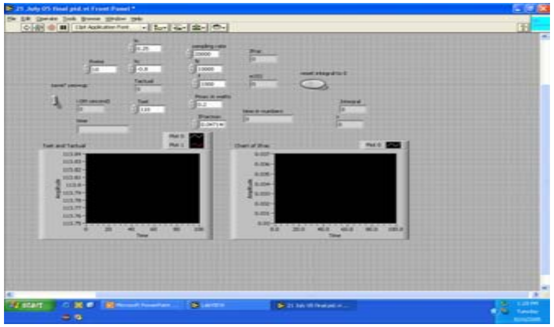
- We skip the Derivative term because it is too noise sensitive.

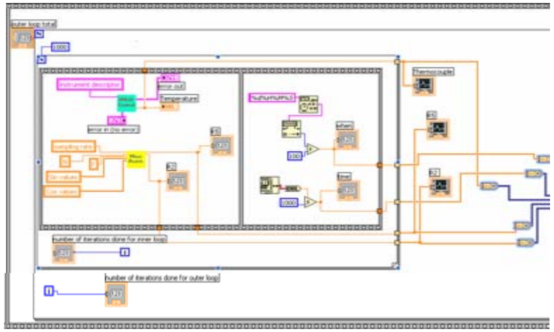


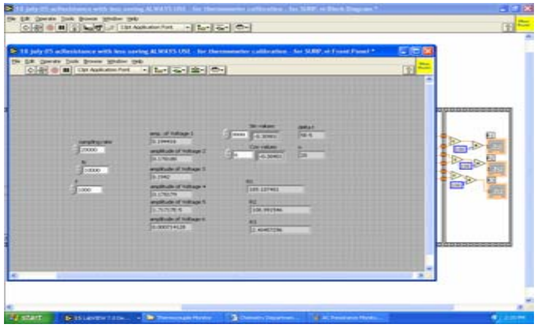
Temperatures (setpoint and actual) as a function of time.

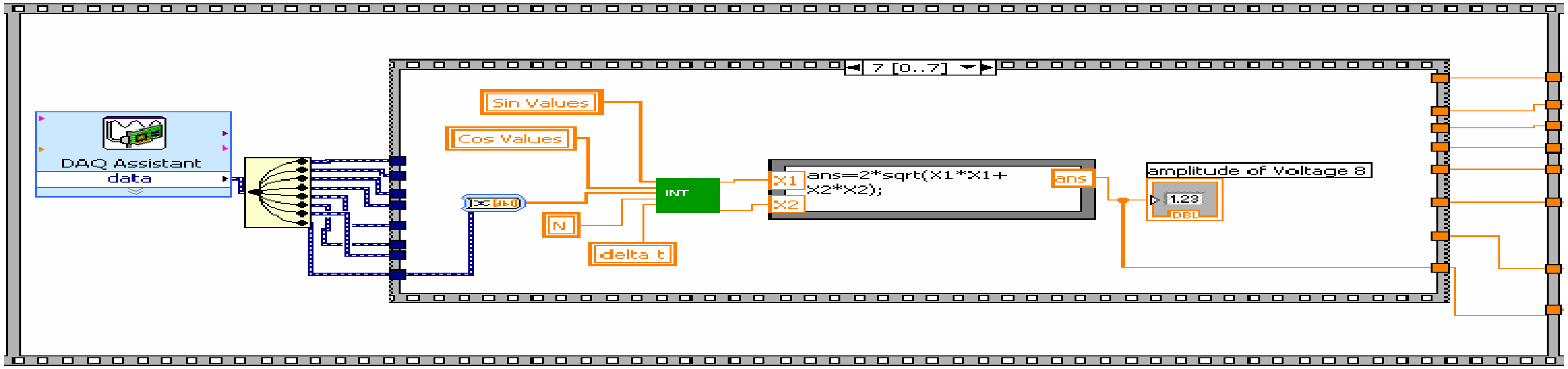
The Computer Interface: Labview Programs

- PID algorithm
- AC Resistance meter to measure temperatures with minimum noise.









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ans=2*sqrt(X1*X1+
X2*X2);
```

AC Resistance Meter: to measure resistance and thus temperature

- Minimizes noise.
- Relies on **Fourier sine and cosine integrals**.

$$I_1 = \frac{1}{T}\int_T V_{th}\sin(\omega t)dt = \frac{1}{T}\int_T V_{th0}\sin(\omega t+\phi_{th})\sin(\omega t)dt$$

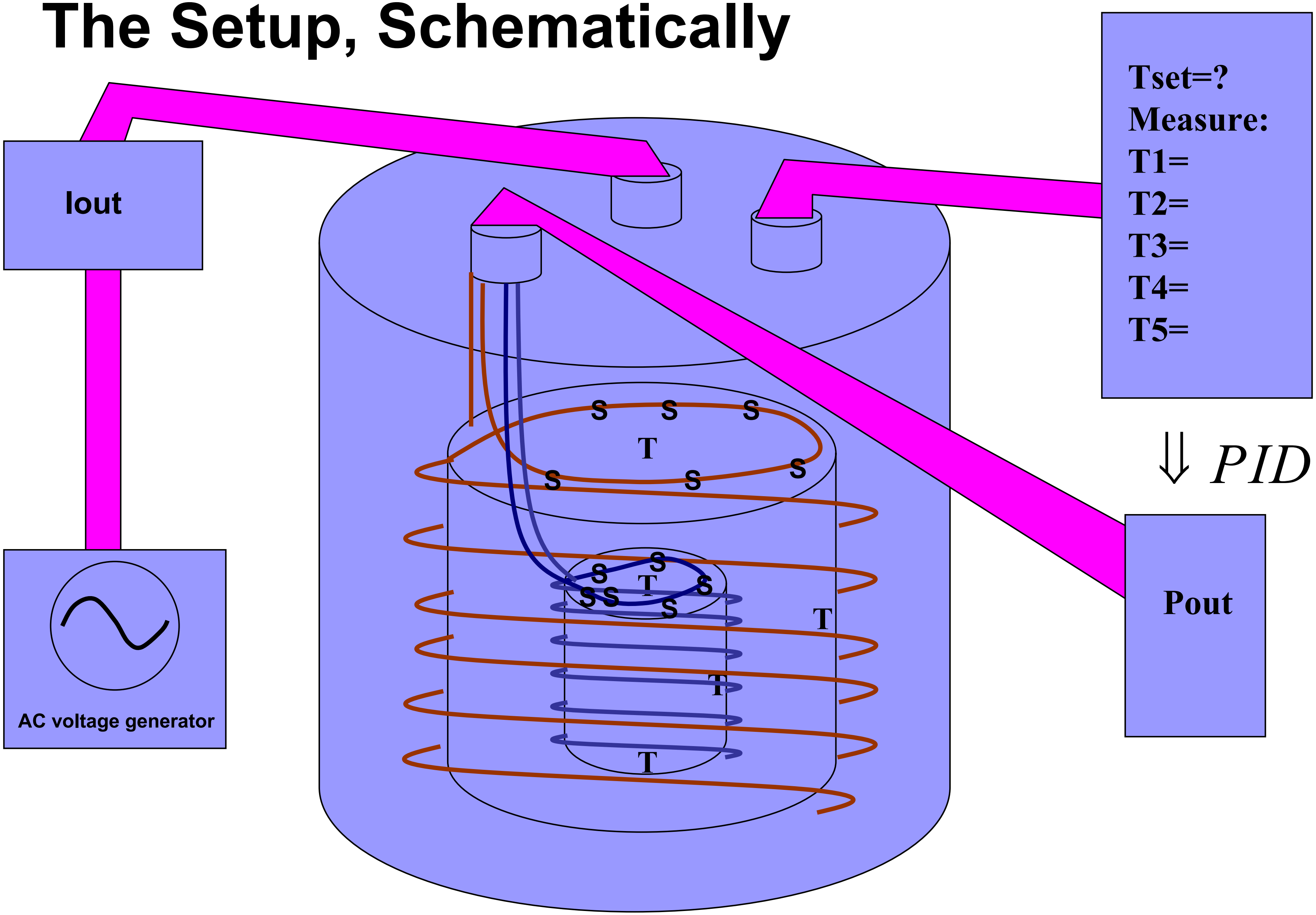
$$I_2 = \frac{1}{T}\int_T V_{th}\cos(\omega t)dt = \frac{1}{T}\int_T V_{th0}\cos(\omega t+\phi_{th})\cos(\omega t)dt$$

Where T = large whole number of periods.

$$\frac{1}{2}\sqrt{I_1^{\,2} + I_2^{\,2}} = V_{th0}$$

- **DC offset and noise** integrate to 0 if T is large.

The Setup, Schematically



Iout

AC voltage generator

Tset=?
Measure:
T1=
T2=
T3=
T4=
T5=

$\Downarrow$ *PID*

Pout

Future Work

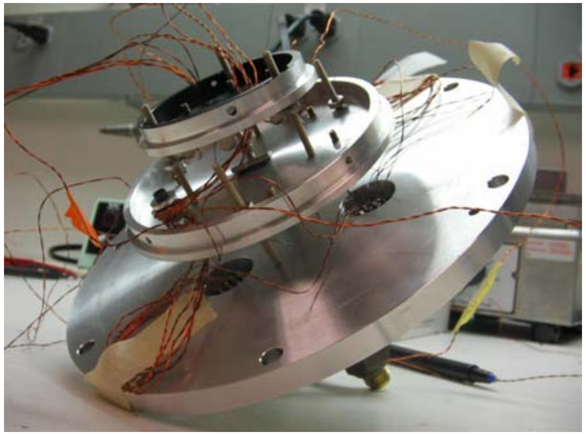
- **Run the experiment!**
- Look at properties of various mixtures.
- Consider the macroscopic cases:

  1. faucet that does not drip.
  2. liquid beading up on a surface.
  3. liquid spreading out on a surface.

- Other systems and other physics.

Acknowledgements: Many thanks to:

- Professor Jerry Seidler for advising.



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