Week 6: Vacuum Systems

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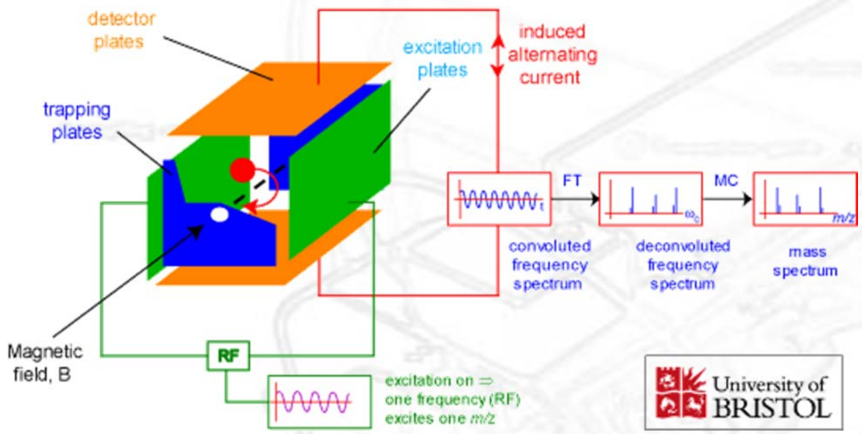
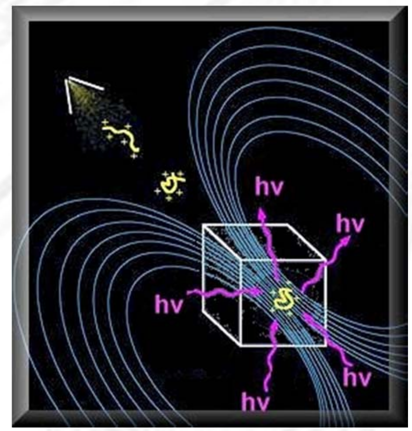
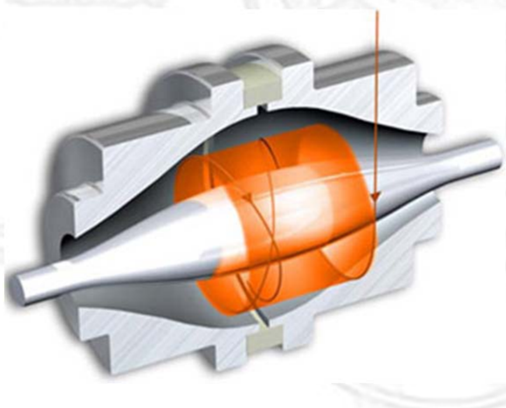
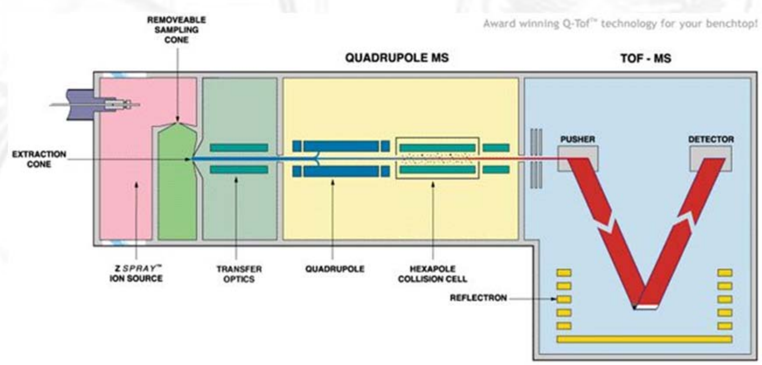
Last Time…

- Fourier Transform Mass Analyzers, Hybrid Instruments, Other Dissociation Methods

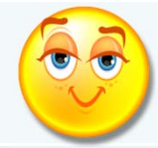
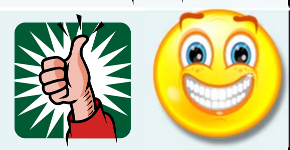
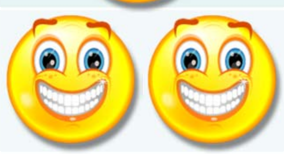
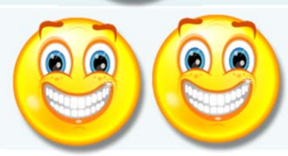








Summing Up Mass Analyzers

Type	Resolution	Mass Accuracy	Sensitivity	MS/MS	Versitility
Sector					
Quadrupole					
Paul Trap					
TOF					
Orbitrap					
FT-ICR					

Vacuum Systems: Who cares?

- Why do we care about vacuum systems? Only because MS can't be done without them!

- You may recall that the first advances in MS were due to the ability to make a decent vacuum.

- Why? It's all about the 'mean free path' λ:

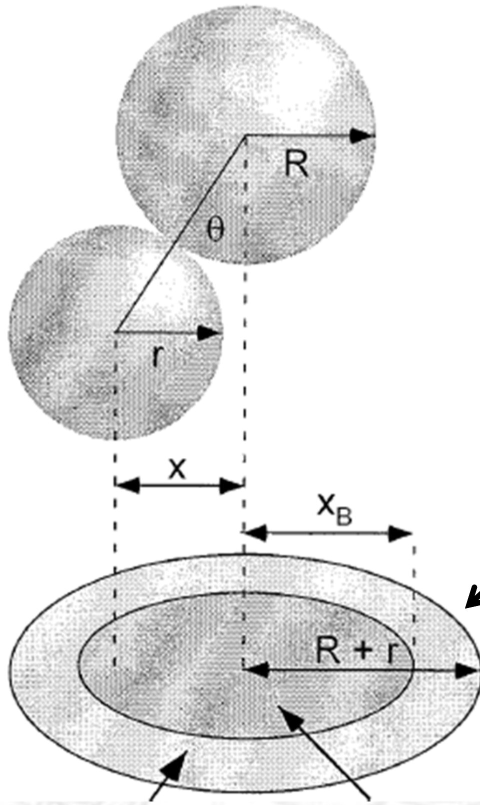
path length = vt

particle density = N/V where N is number of particles and V is volume

collision cross section = $\pi(r_1 + r_2)^2$ where r_1 and r_2 are the radii of the colliding particles

Collision Cross Section

• The collision cross section is an important concept, particularly in ion mobility.



collision cross section is the area of this circle

• Notice how we are assuming that the colliding particles are spherical…hmmmm….

The Mean Free Path

- The mean free path is the average distance that a particle will travel before colliding with another particle.

- Example: Lets say our favorite ion [DEREK+H]$^+$ is flying though a 1 m TOF tube (radius 0.1 m) at a pressure of $5x10^{-8}$ Torr of N_2 at room temp.

- First, lets calculate the number of particles, N.

P (torr $\rightarrow$ atm)

V ($m^3 \rightarrow$ L)

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Mean Free Path Calc. Cont.

- Now we can calculate the particle density:

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- How about the collision cross section:

( ) (( ) ( ))

- Finally, the mean free path:

( ) ( )

Measuring Low Vacuum

• Measurement of low vacuum is relatively easy because there is still plenty of gas around…

• Pirani gauges simply measure resistance in a (usually platinum) wire exposed to vacuum. Current heats the wire up (resistance goes up), collisions with ambient gas cool the wire down (resistance goes down).

• Obviously no good if there isn't enough gas around to cause a measurable change in resistance.

• Pirani gauges are very accurate down to about 10^{-4} torr.

Measuring High Vacuums

• These days, MS instrument operate at 'high vacuum', i.e. anything lower than 10^{-7} torr.

• The cheapest high vacuum measuring device is a Penning or Cold Cathode gauge.

• Electrons are generated via discharge in a cold cathode. Electrons flow to the anode and collide with gas particles, ionizing them. These ions are collected in an 'ion collector' (negatively charged cup).

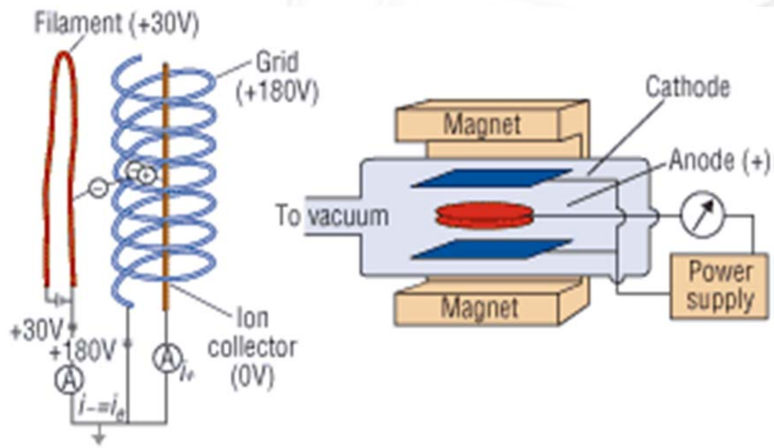
• These gauges have upper pressure limit because if there is too much recombination, there is no current.

• On the other hand, if pressure too low, no discharge at cathode.

• Effective measurement range: $10^{-5} – 10^{-9}$ torr

Measuring High Vacuums Cont.

• The second cheapest, the Bayard-Alpert or Hot Cathode gauge works on a similar principle:



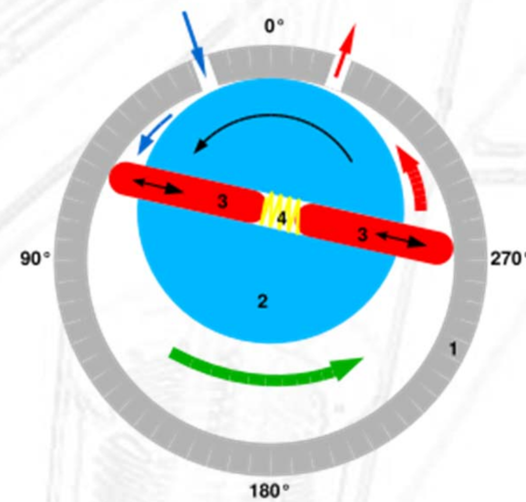
• Electrons generated from a heated filament ionize gas, which is drawn to a negatively charged filament inducing a measurable current. Electrons are discharged on a positively charged grid.

• Pressure range = 10^{-3} to 10^{-10} torr.

Making a low Vacuum

- Because of how we are going to make a high vacuum, we first need to make a low vacuum, maybe 5×10^{-4} torr or so...

- To do this, we use a Rotary Vane pump:



- These pumps have a slow pumping speed (about 3 L/min) but can handle a lot of gas/volume (i.e. they can run at high pressure).

- They are also exceedingly tough.

Making High Vacuum

- Once we have a low / medium vacuum, we can use high flow pumping devices to make a high vacuum.

- The most common type is the turbomolecular pump, which is built like a jet engine:

- The mechanism is simple: Gas particles diffuse into the fan blades and are physically knocked away from the vacuum and into the pump.

- Successively flatter blades ensure that the particle keeps going in the right direction.

Turbomolecular Pumps

- The main advantage of tubopumps is that they require relatively little power (~ 100W) and can generate an oil-free vacuum.

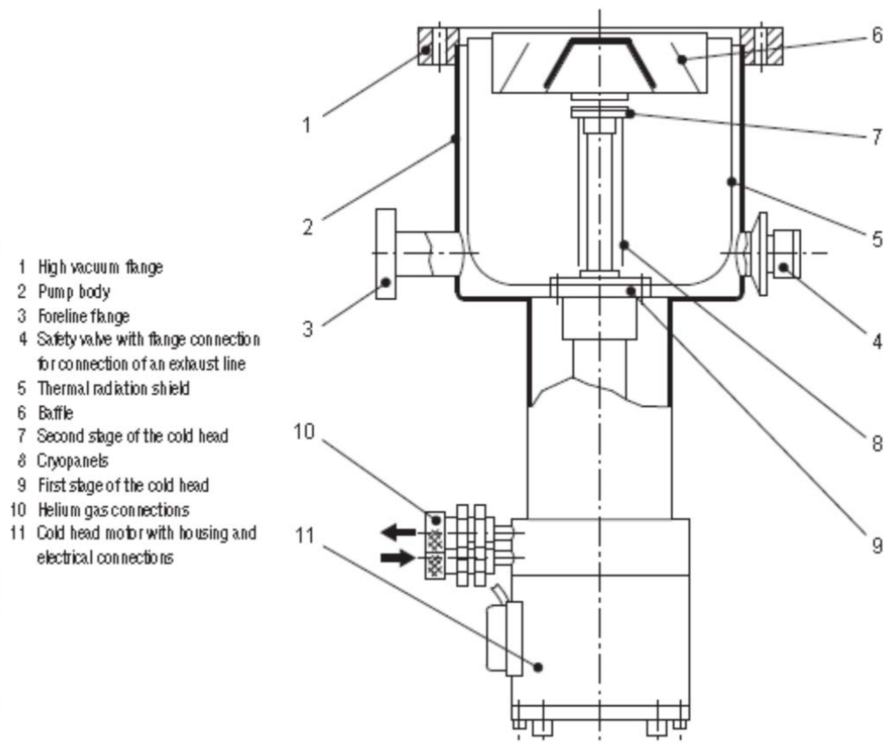
- The main disadvantage is that they are expensive and prone to sudden breakage (not unlike a hard drive or anything else that spins).

- Pumping speed is around 300 L/sec.

- The fan blades spin at 50 – 60,000 rpm. Obviously, we cannot do this at high pressure!

Cryopumps

- Need a super-high vacuum? Try a cryopump:



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- These pumps work by condensing gas onto a surface that is cooled to lN_2 temperatures.

Cryopumps

- Cryopumps cannot be used at high pressures because the adsorbent surface quickly becomes saturated. Thus they must be operated with a backing pump, or even a vane pump + turbomolecular system.

- In return, cryopumps offer extremely high pumping speeds, up to 1500 L/s.

- This allows them to achieve the highest vacuum = 10^{-12} torr or better if a colder cryogen is used.

- One disadvantage is that, even at high vacuum, the adsorbent eventually becomes saturated and must be replaced from time to time (which must be done out of vacuum).

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