Radon Reduction System For LZ Dark Matter Experiment

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On behalf of the Michigan LZ group

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UNIVERSITY OF MICHIGAN

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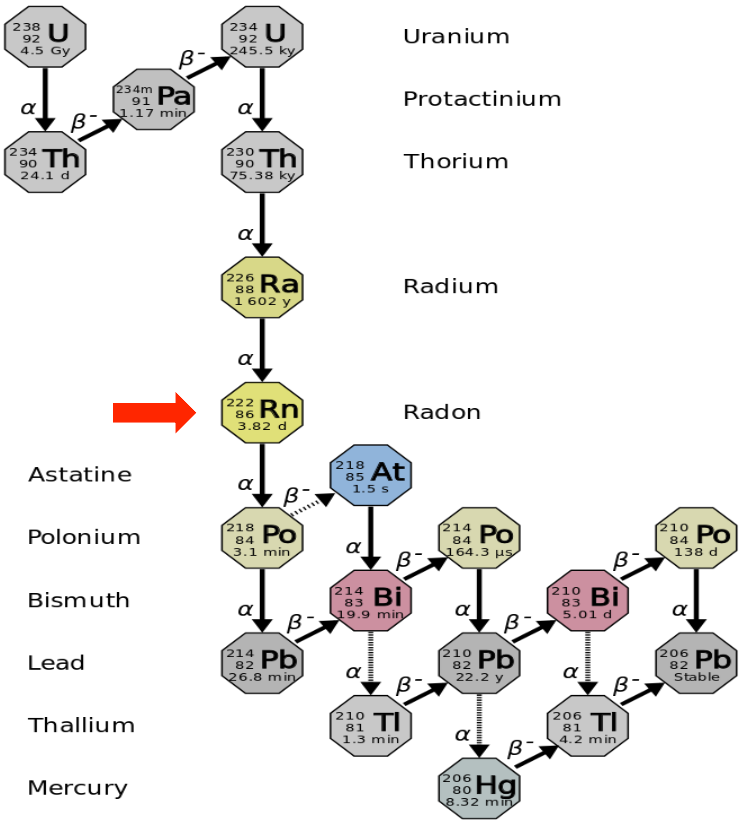
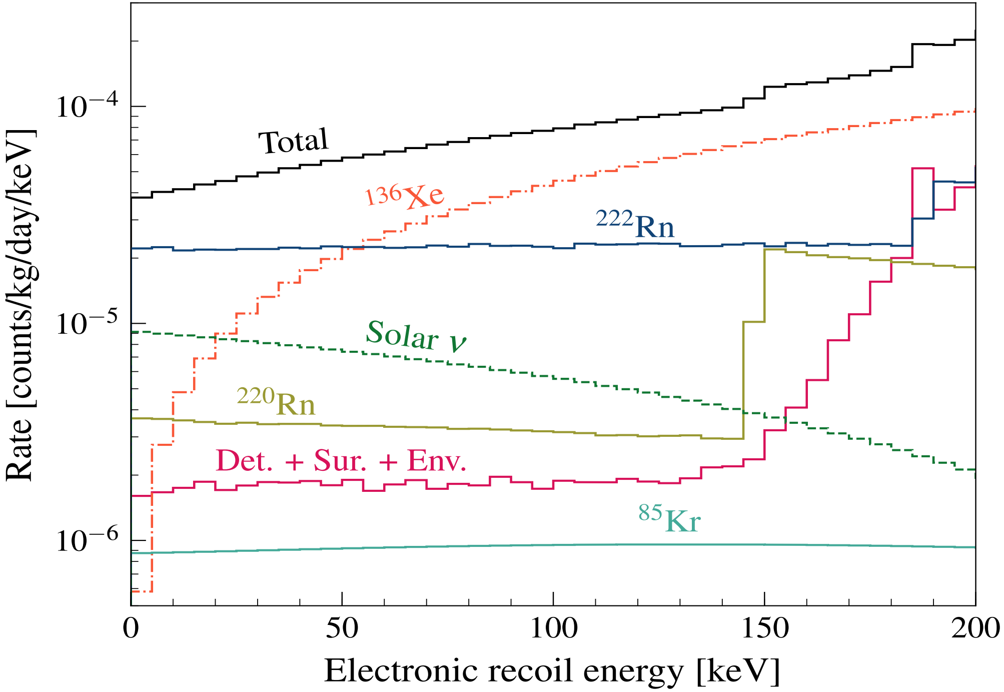
Radon—Where is it from & Why is it bad ?



- ^{222}Rn is a product of ^{238}U decay
  - mean life of τ_{Rn} = 5.516 day
- Trace amounts of ^{238}U in detector components: *radon emanation*
  - ^{222}Rn is *CONTINUOUSLY* resupplied
  - Particularly high from warm parts with large surface area
- It dissolves in liquid xenon
  - Cannot be removed by hot purifying getters
- β-decay of ^{214}Pb mimics WIMP signal
  - Survives the conventional charge/light discrimination cut, if present in high enough level.

Rn contribution to LZ background spectra



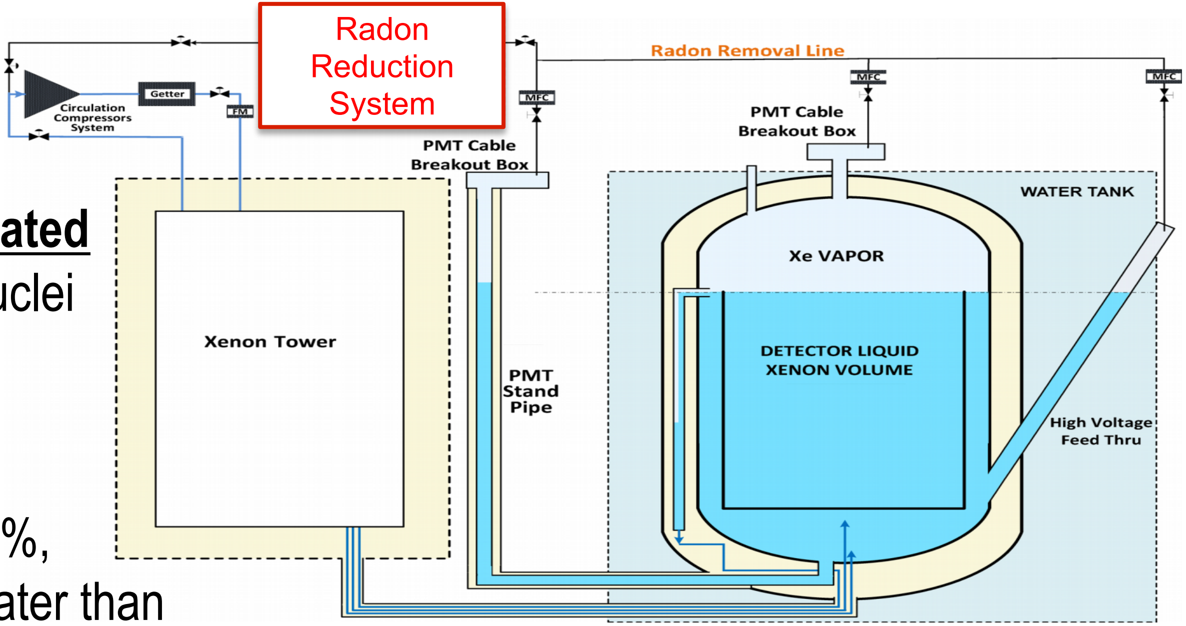
Projected WIMP sensitivity of the LZ Experiment
arXiv:1802.06039

The background spectra in the 5.6 ton fiducial volume of the LZ TPC for single scatter events

^{222}Rn is the dominant ER background in the WIMP dark matter search window (1.5 and 6.5 keV_{ee})

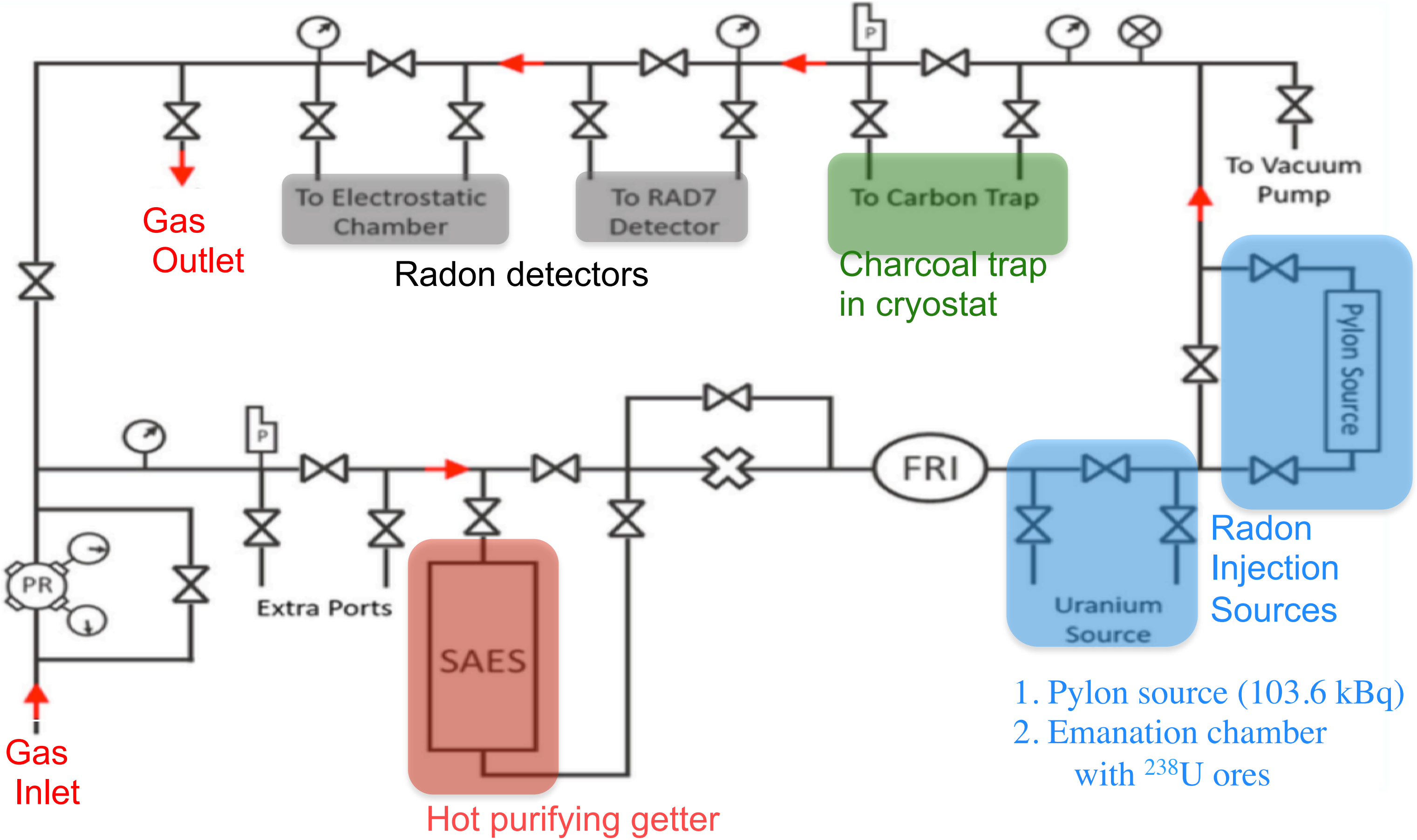
In-line radon reduction system for LZ

The LZ goal is to reduce ^{222}Rn background of the warm sections (cables and feedthroughs) by at least an order of magnitude.



- Sequestration of atoms in **activated carbon trap** until most ^{222}Rn nuclei decay
  - As in ***gas chromatography***: $v(Xe)/v(Rn)$ (-85 C) ≈ 1000
- In order to obtain removal of 90%, sequestration time must be greater than $\ln(10)\cdot\tau_{Rn} = 12.7$ days

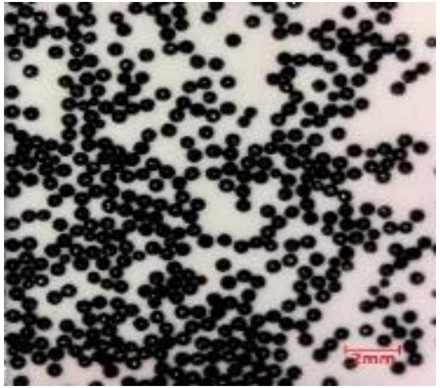
Radon reduction system R&D at Michigan



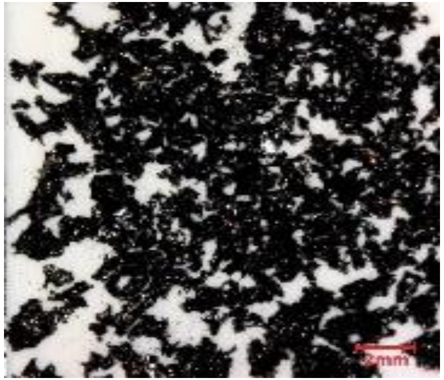
1. Pylon source (103.6 kBq)
2. Emanation chamber with ^{238}U ores

Different activated charcoals tested

Saratech



CarboAct

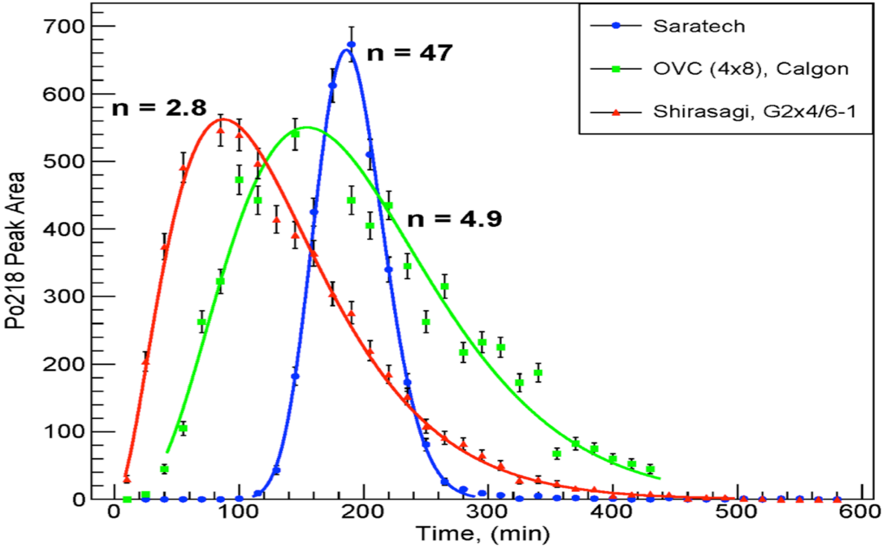


Shirasagi

Charcoal	Density (g/cm^3)	Surface area (m^2/g)	Spec. activity (mBq/kg)	Price ($/kg)
Shirasagi	0.45	1,240	101 ± 8	27
CarboAct	0.28	1,000	0.23 ± 0.19	15,000
Saratech	0.60	1,340	1.71 ± 0.20	35
Saratach (HNO_3)	**0.60**	**1,340**	**0.51 ± 0.09**	**135**

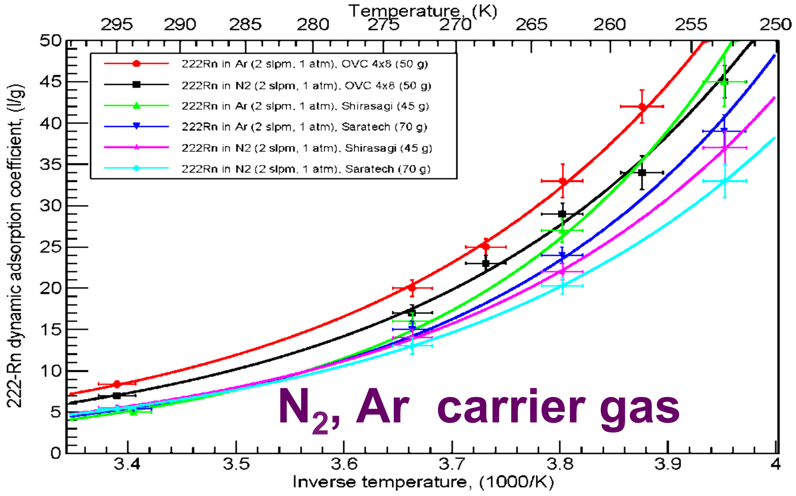
Elution curves for Ar in a 0.1l trap at 293K

- ^{222}Rn adsorption characteristics on various charcoals were studied in N_2, Ar, and Xe carrier gases.
- By measuring the ^{218}Po spectra after ^{222}Rn injection, elution curves were obtained.
- **Vastly different transition times for various charcoal types.**
- **Saratech displays superior performance**

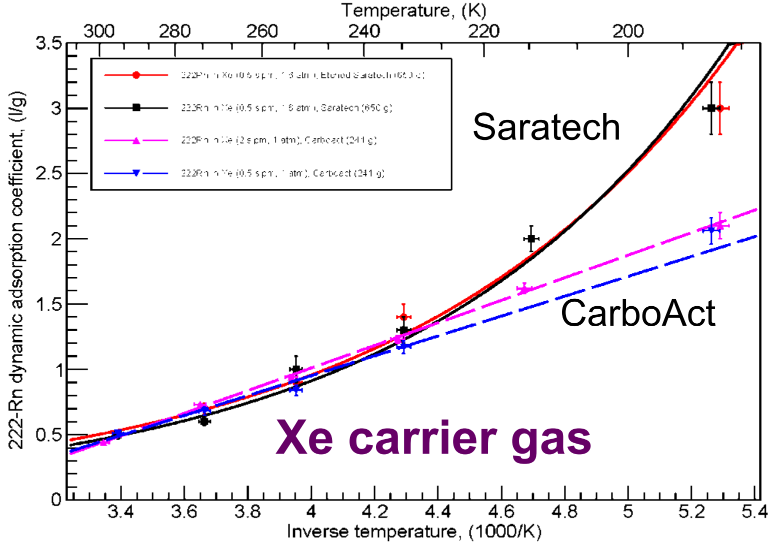


$$y\left(\frac{t}{\tau}\right) = \frac{\alpha n^n}{(n-1)!}\left(\frac{t}{\tau}\right)^{n-1} e^{-n\frac{t}{\tau}}$$

k_a — the dynamic adsorption coefficients



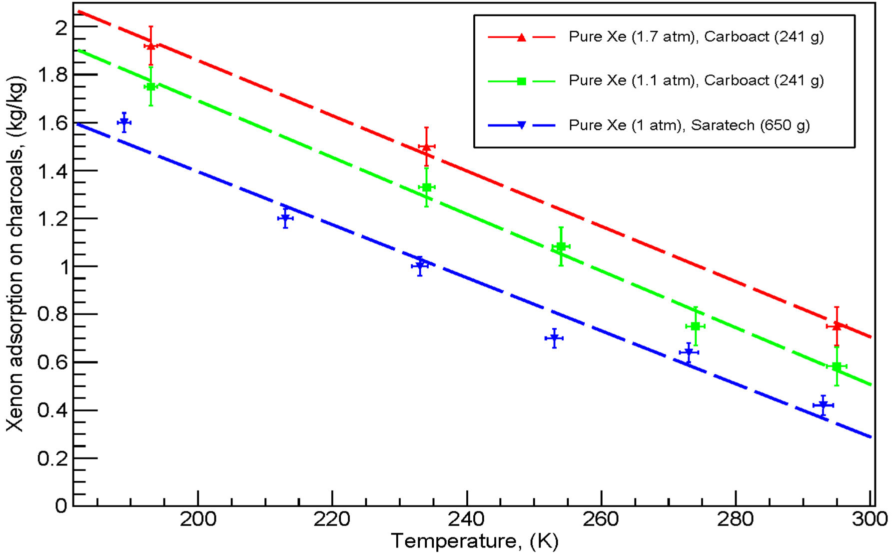
- τ, the average breakthrough time for radon is related to the absorption coefficient by $\tau = \frac{k_a m}{f}$, obtained from the fits to the elution curves



- Expectations:
  - **N_2 and Ar** carrier gas follow exponential rise with inverse temp **(Arrhenius law)**
  - **Xe** carrier gas on **Saratech follows Arrhenius law**
- Surprises:
  - **Xe** carrier gas on **CarboAct violates Arrhenius law**
  - **k_a with Xe** carrier gas is about **10x – 50x smaller than in N_2, and Ar** carrier gas

Adsorption of xenon on charcoal

- **Xe atoms** tend to **occupy the charcoal adsorption sites** much faster resulting in the **short ^{222}Rn breakthrough times**
- Xe adsorption in charcoal at -85C is large: **~1.6 kg/kg** (in Saratech) at atmospheric pressures
- Adsorption of N_2 and Ar gases was below detection limit of the scale, (below 20 g/kg of charcoal)



Xe adsorption on charcoal:

- Increases linear with decreasing Temp.
- Increases only slightly with pressure
- Depends only weakly on charcoal type

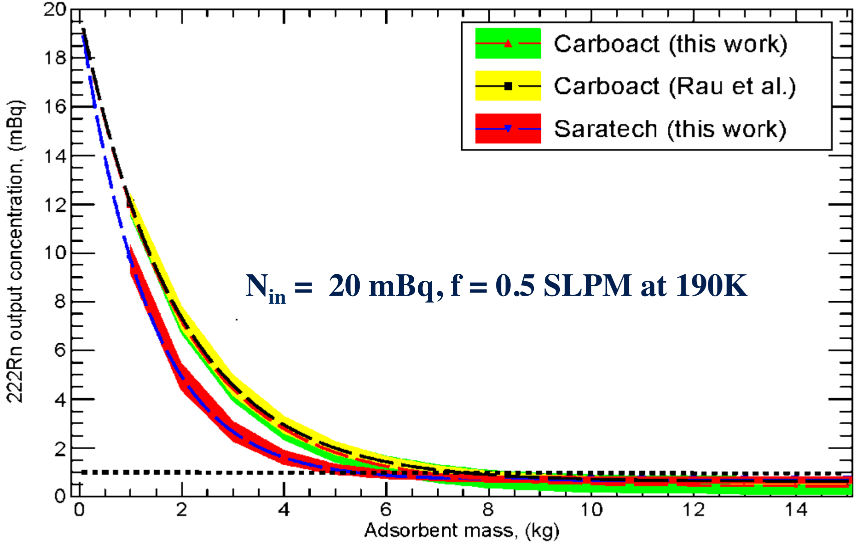
Designing a radon trap

- **Lowest achievable Rn concentration is limited by specific activity (s_0) of charcoal**
- ~7 kg of etched Saratech will reduce Rn concentration from warm cables and feedthroughs at the output of the trap below 1 mBq
- Although CarbAct has lowest s_0, not most efficient trap material for small traps

$$N_{out} = N_{in} e^{-\frac{k_a \cdot m}{f \cdot \tau_R}} + s_0 f \frac{\tau_R}{k_a}\left(1 - e^{-\frac{k_a \cdot m}{f \cdot \tau_R}}\right)$$

Due to Rn in GXe

Due to activity of the charcoal



Conclusion

- ^{222}Rn breakthrough times in Xe carrier gas are much shorter than in N_2 and Ar carrier.
- Among the investigated charcoals, Saratech appears to be the most efficient ^{222}Rn reduction material.
  - Chemical etching of Saratech with HNO_3 acid reduced the intrinsic radioactivity (^{238}U) by about a factor of three.
  - Etching did not affect ^{222}Rn adsorption characteristics of Saratech making it a strong candidate for a trap.
- Published in NIM journal: A 903 (2018) 267–276

U-M LZ Deliverable

- Using the findings from our R&D studies we have built an in-line radon reduction system for LZ detector
  - It will contain 11kg of etched Saratech charcoal at -85^{0}C
  - It is designed for 0.5 SLPM Xe gas flow rate

Thank You!

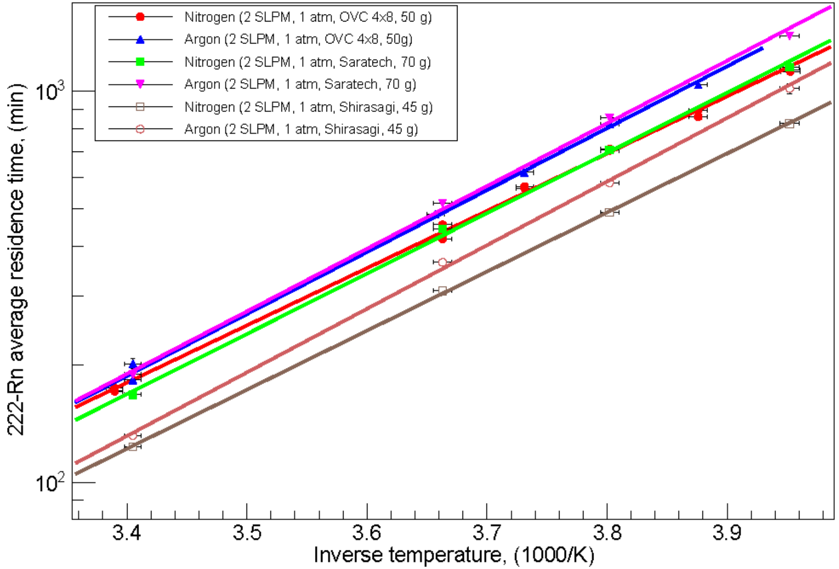
Any questions ?

Arrhenius Law

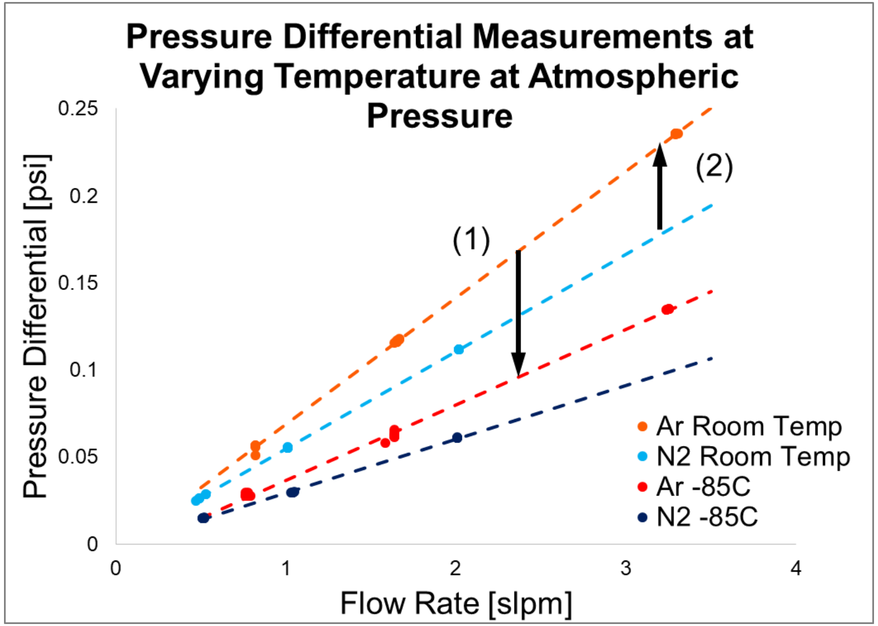
Describes temperature dependence of chemical reaction rates.

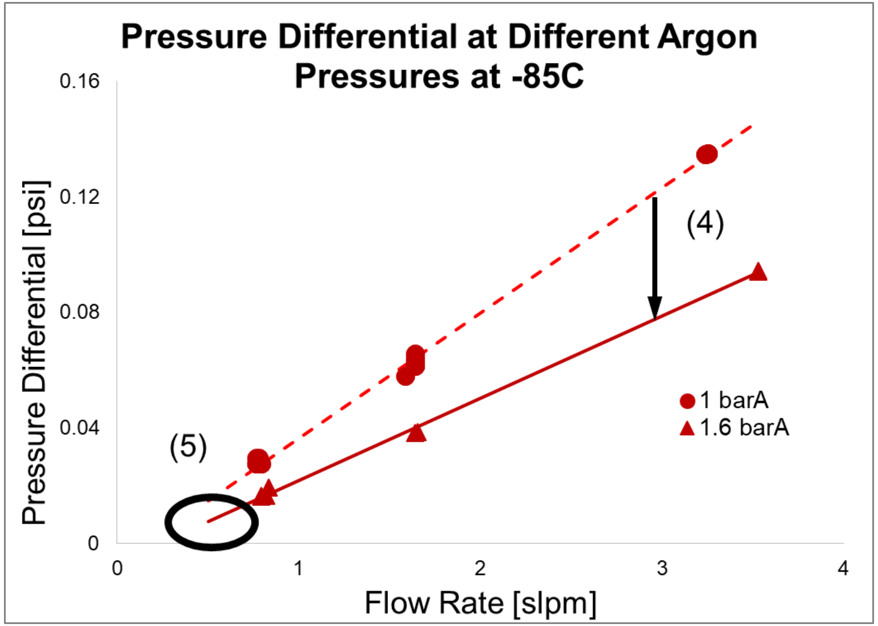
$$k = Ae^{\frac{-E_a}{k_b T}}$$

- k: rate constant
- E_a: activation energy (J)
- k_b: Boltzmann constant (J/K)
- T: temperature (K)



Flow Impedance in Radon Trap





- ΔP decreases by a factor of 2 when going from room temperature to -85C
- ΔP is a factor of 1.3 higher for Ar than for N_2

- ΔP is lower at higher operating pressures
- At LZ operating pressure and temperature, ΔP is only ~0.01 psi!