Vacuum Experiment: Week 3

AP 4018
Columbia University

Week 3 Objectives

- Option 1:

  ➡ Measure the conductance of gas through pipes

  ➡ Compare/discuss your results w.r.t. vacuum conductance formulas

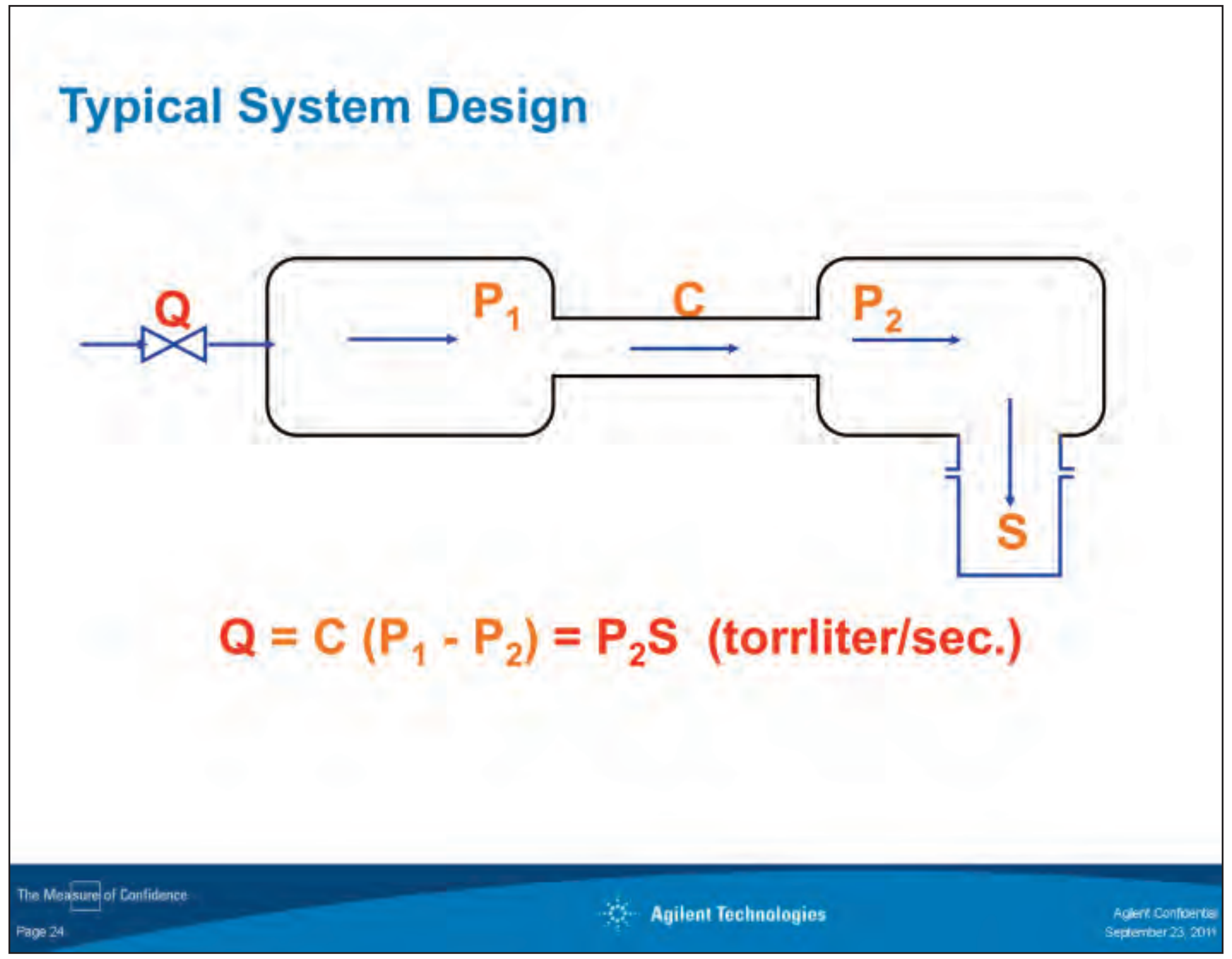
- Option 2:

  ➡ Measure outgassing of vacuum system as chamber temperature rises

  ➡ Discuss with basic considerations of atomic/molecular adsorption

Introductory Reading (Option 1)

- Please see class homepage at: http://sites.apam.columbia.edu/courses/ap4018y/, and read background information about vacuum science and technology…



Throughput

Throughput is the actual amount of gas – or the number of atoms and/or molecules – moving through or being removed from a vacuum system. This is the work really being done by a vacuum system. Throughput is expressed by the letter Q.

The flow of gas through a pipe is described as the amount of gas (Q) flowing through a pipe is equal to conductance (C) of the pipe times the pressure (P1 – P2) over the pipe.

Or: $Q = C \times (P_1 - P_2)$

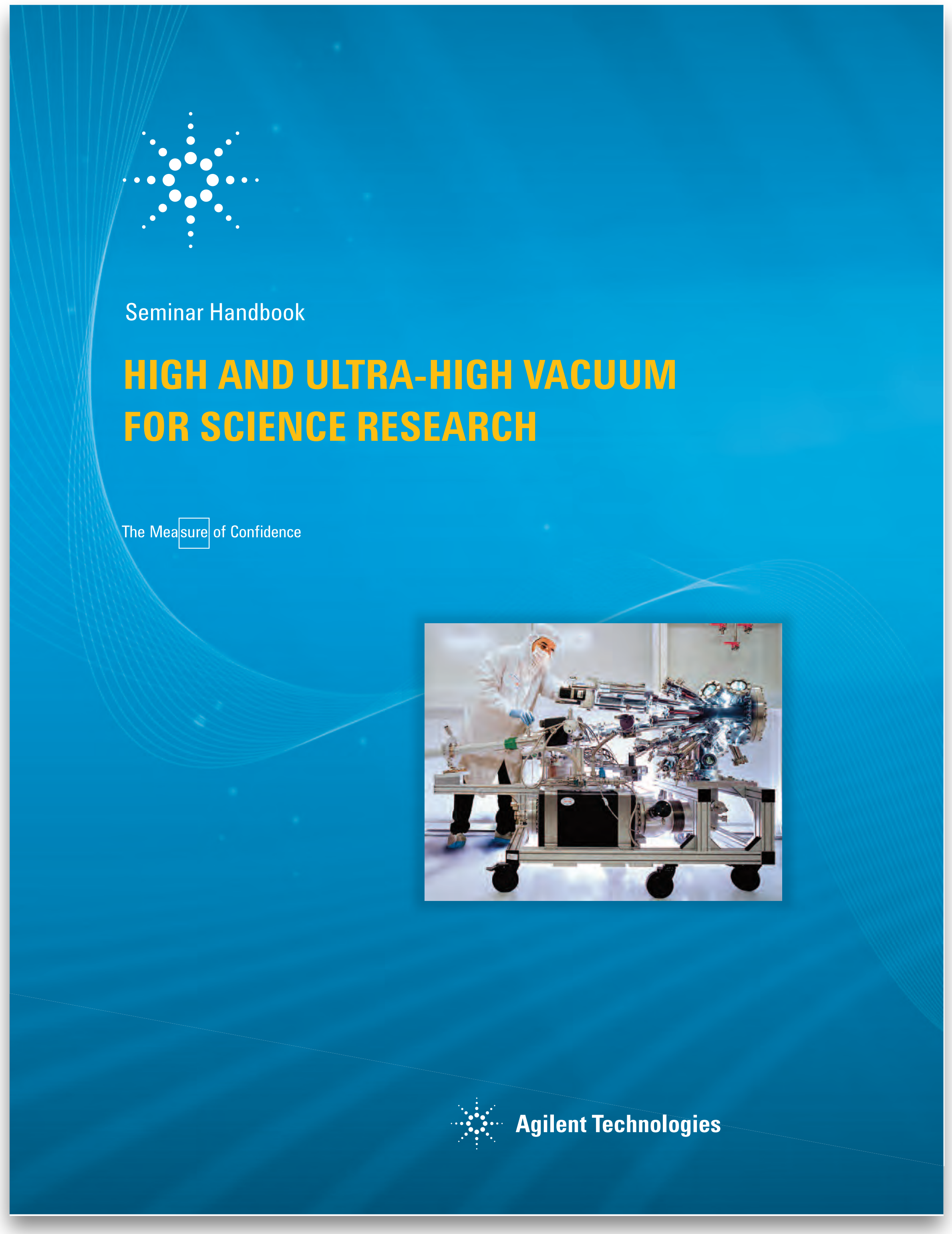
For the case where a pump is removing gas from a chamber at pressure P, we can look at how throughput is related to pumping speed (S) by taking another look at the definition of speed

Pumping Speed: $\frac{\text{amount of gas flowing into a chamber}}{\text{pressure in the chamber}}$

or: $S = \frac{Q}{P}$ (liters/second)

reworking this formula:
$Q = P \times S$ (torrliters/second)

Very Good Introduction…

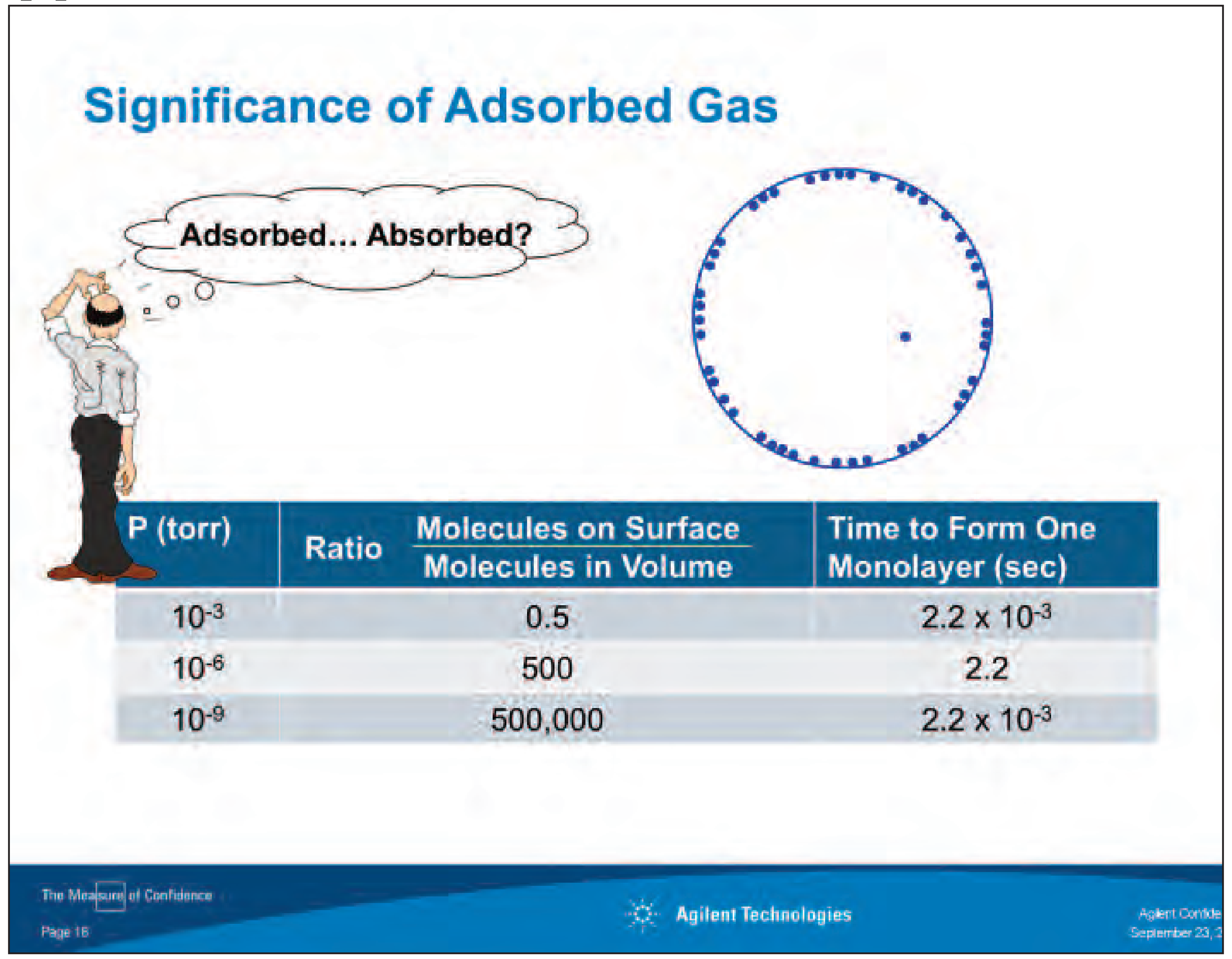


http://sites.apam.columbia.edu/courses/ap4018y/UHV_Seminar_Handbook.pdf

Introductory Reading (Option 2)

- Please see class homepage at: http://sites.apam.columbia.edu/courses/ap4018y/, and read background information about vacuum science and technology…

Very Good Introduction…



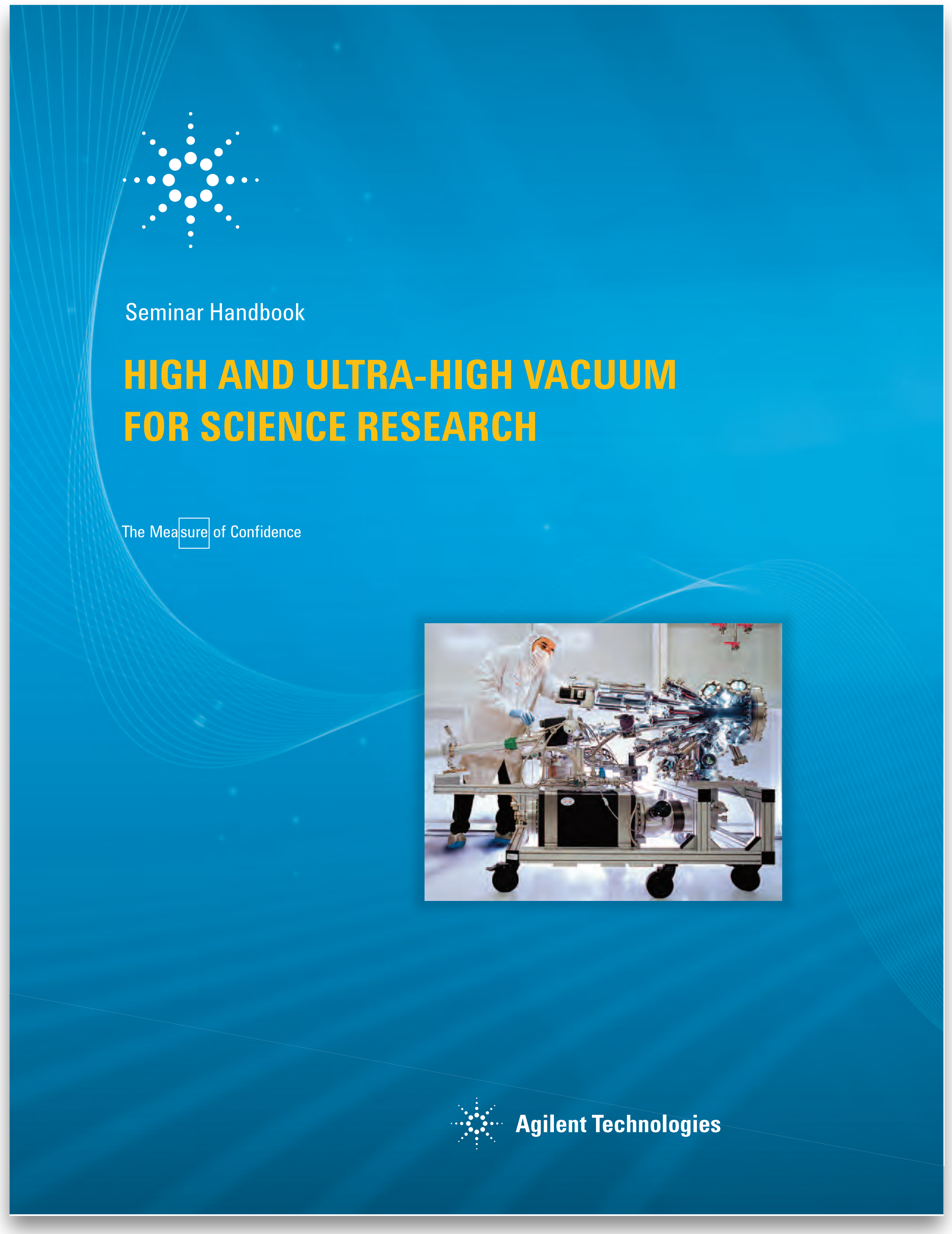
P (torr)	Ratio: Molecules on Surface / Molecules in Volume	Time to Form One Monolayer (sec)
10^{-3}	0.5	2.2×10^{-3}
10^{-6}	500	2.2
10^{-9}	500,000	2.2×10^{3}

Notes

Adsorbed Gas

The diagram above illustrates the fact that once the pressure in a high vacuum system has reached high vacuum levels, most gas resides on the walls of the system. At a pressure of 1×10^{-6} torr there are 500 molecules residing on the walls of the system for every molecule moving through the system.

This highlights the fact that at high vacuum and ultra-high vacuum levels, the pressure in the system is determined by the surface gas in the system. The right column in the diagram shows that it only takes 2.2 seconds to coat a perfectly clean system (a system without a single molecule in it!) with a monolayer of gas when it exposed to that gas at a pressure of 1×10^{-6} torr. At 1×10^{-9} torr it will take 2,200 seconds to coat the system with one monolayer. This explains why surface analysis equipment usually operates at ultra-high vacuum pressures.



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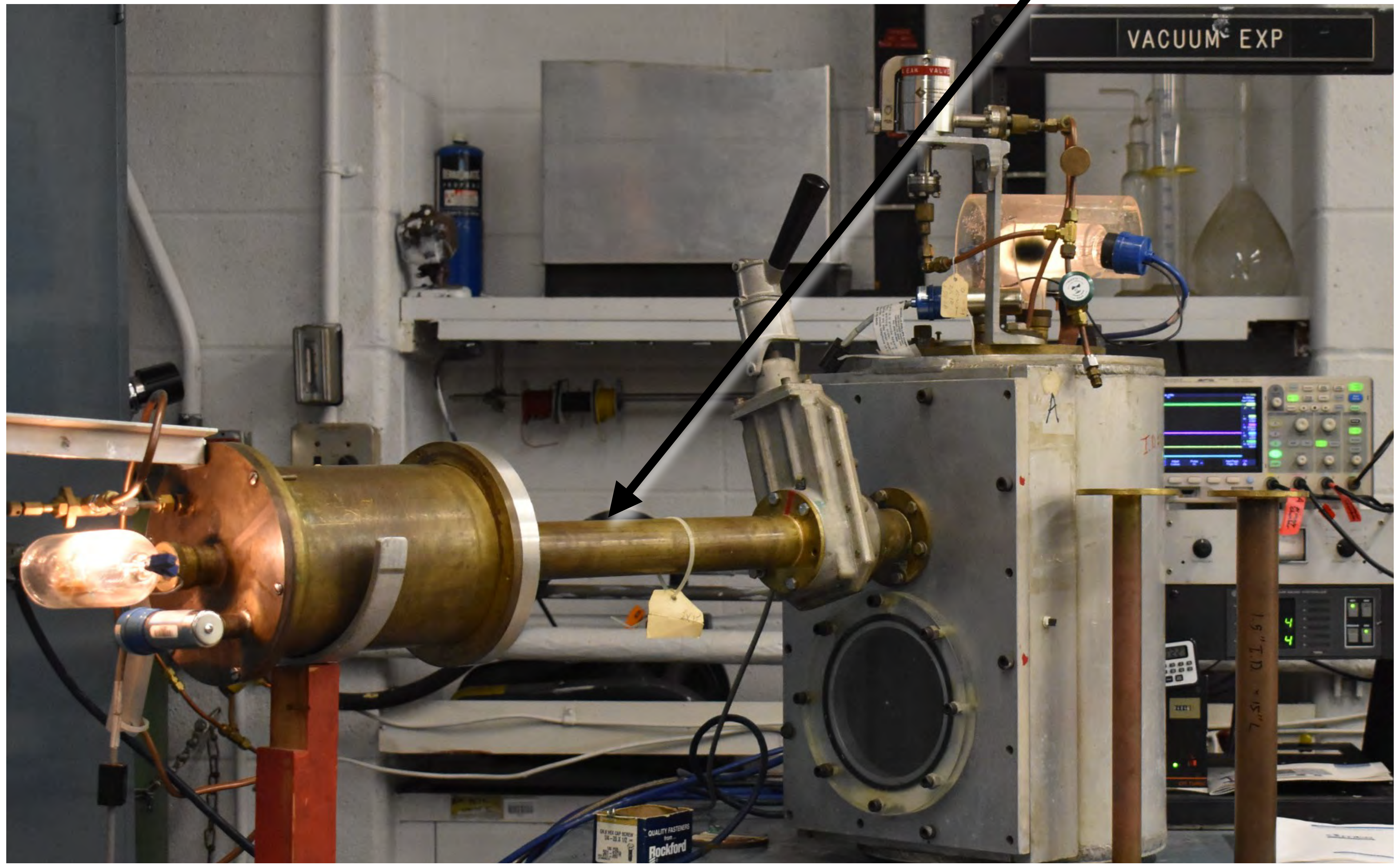
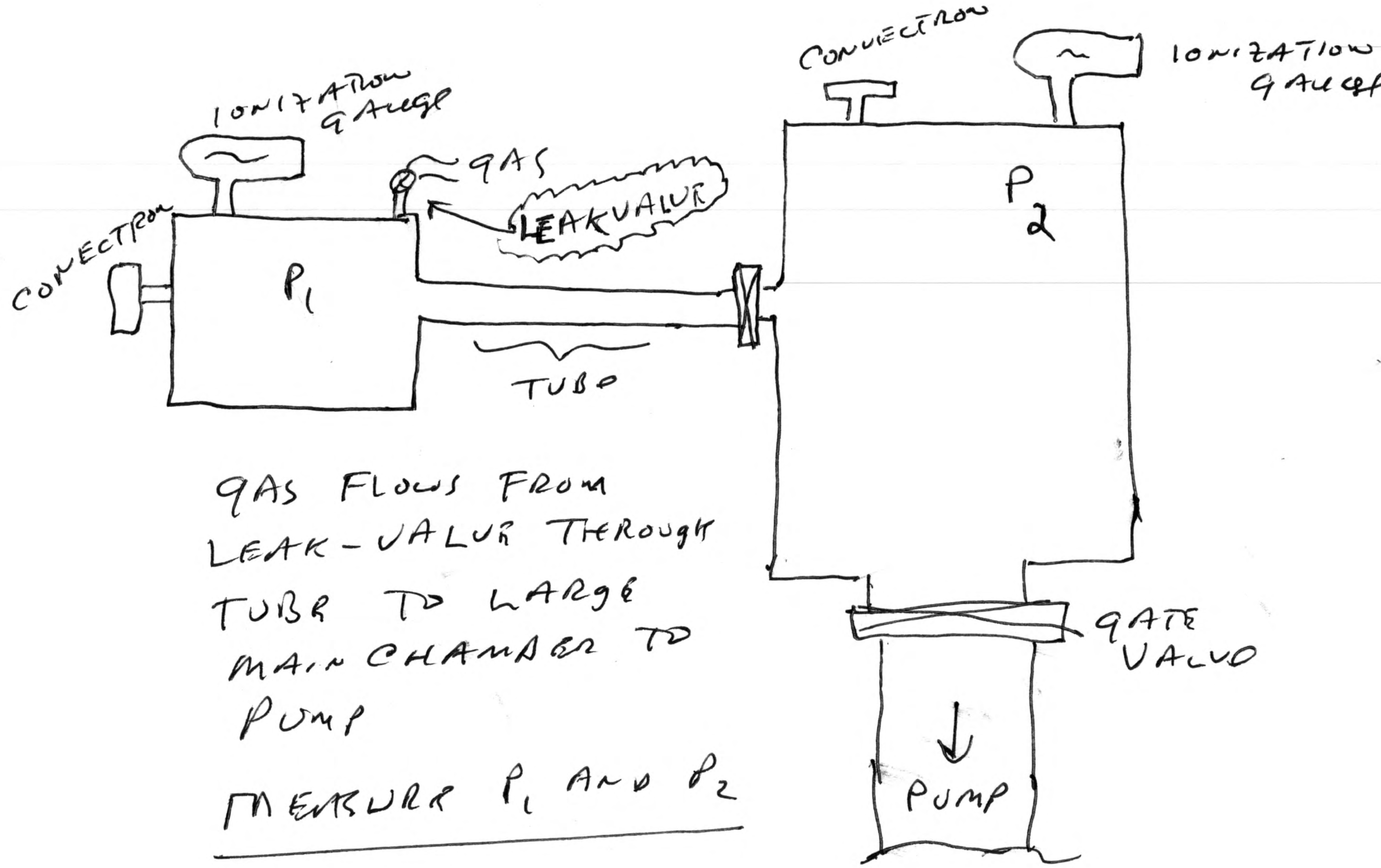
Overview of Week 3 (Option 1)

Auxiliary Chamber

Tube





Ionization Gauge Pressure indication:

$P_i = 10^{(V-11)}$ Torr or mbar

where V is controller output in Volts

Calculate conductance = $(P_1 - P_2)/Q_{leak}$

Overview of Week 3 (Option 1)

Calculate conductance = $(P_1 - P_2)/Q_{leak}$

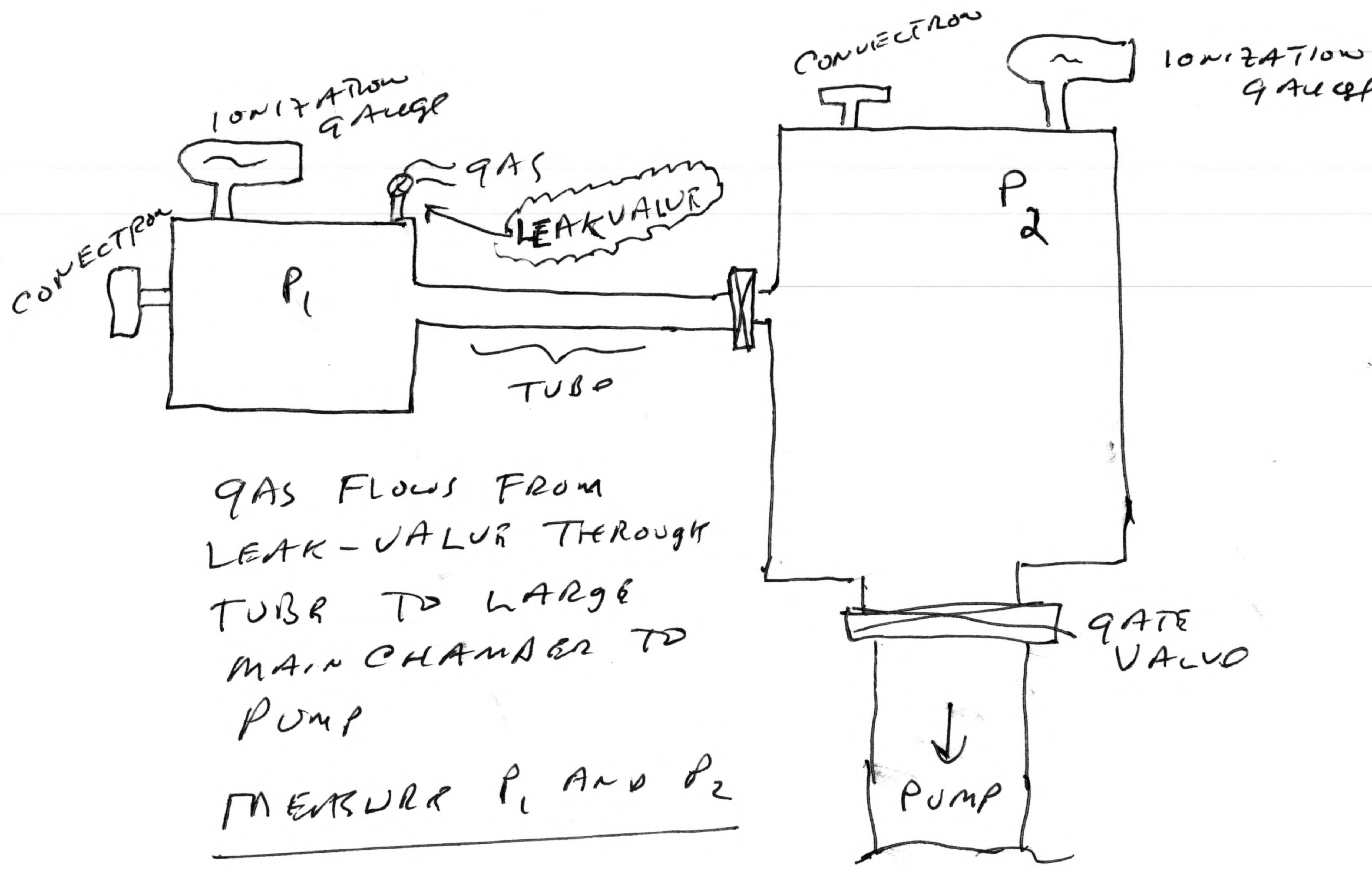
What is Q_{leak}?

Answer:

$Q_{leak} \approx S\,P_2$

where S is measured from Week #2.

$\therefore C \approx (P_1/P_2 - 1)/S$



Notes about Conductance

- See notes online
- Recall: two vacuum regimes
  - **Molecular regime** (long mean free path), when the conductance is independent of pressure and depends only upon pipe size
  - **Viscous regime** (short mean free path), when the conductance is proportional to the pressure (and the pipe dimensions.)
  - Roughly, when P(mTorr) > 27/D (with D = pipe diameter in inches), then flow is in viscous regime.

Notes about Conductance

With Conductance in l/s, diameter D in inches, and pipe length L in inches, then useful formula are:

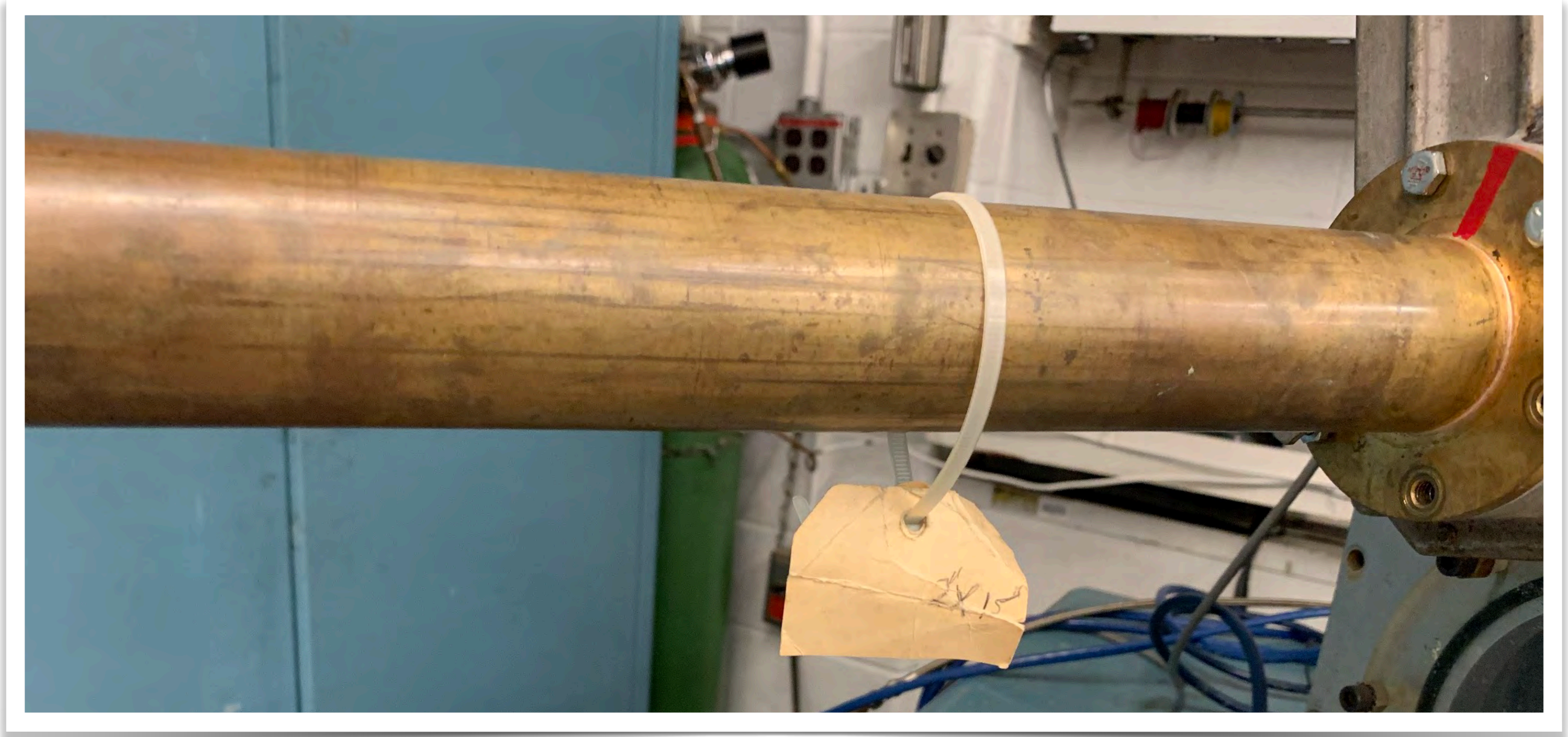
$$C = 79\frac{D^3}{L}$$

Molecular Flow

$$C = 2.94\frac{PD^4}{L}$$

Viscous Flow

Tubes (Only 1” and 2” Used)

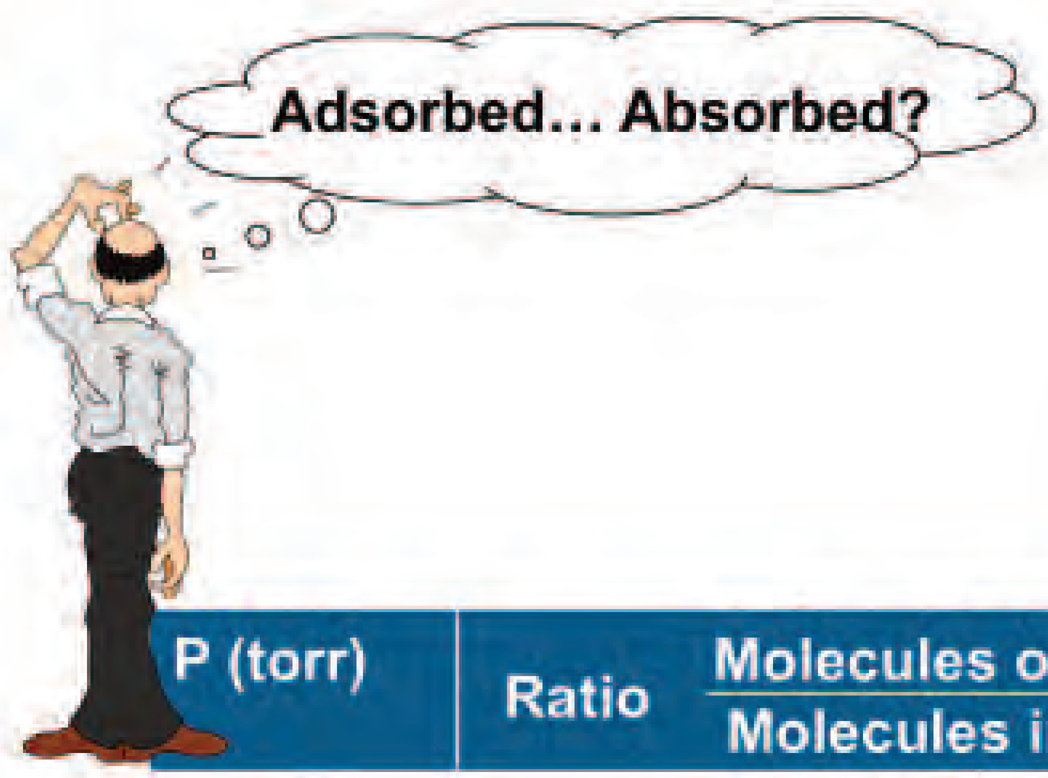


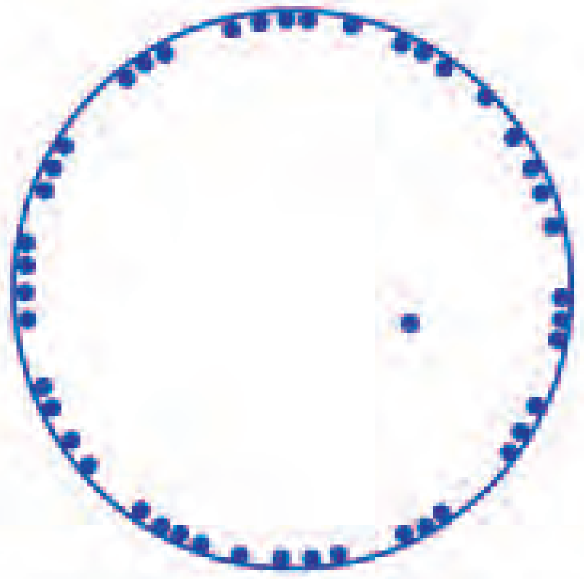
2-inch diameter

1-inch diameter

Overview of Week 3 (Option 2)

Significance of Adsorbed Gas





P (torr)	Ratio $\frac{\text{Molecules on Surface}}{\text{Molecules in Volume}}$	Time to Form One Monolayer (sec)
10^{-3}	0.5	2.2×10^{-3}
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Vacuum Characteristics

Pressure (torr)	Molecular Density (molecules/cm^3)	Molecular Incidence (molecules/cm^2/sec)	Mean Free Path (cm)	Monolayer Formation Time (sec)
760	2.47×10^{19}	3.14×10^{23}	6.7×10^{-6}	2.9×10^{-9}
1	3.25×10^{16}	4.13×10^{20}	5.1×10^{-3}	2.2×10^{-6}
10^{-3}	3.25×10^{13}	4.13×10^{17}	5.1	2.2×10^{-3}
10^{-6}	3.25×10^{10}	4.13×10^{14}	5.1×10^{3}	2.2
10^{-9}	3.25×10^{7}	4.13×10^{11}	5.1×10^{6}	2.2×10^{3} (37 min)
10^{-12}	3.25×10^{4}	4.13×10^{8}	5.1×10^{9}	2.2×10^{6} (25.5 days)

Overview of Week 3 (Option 2)

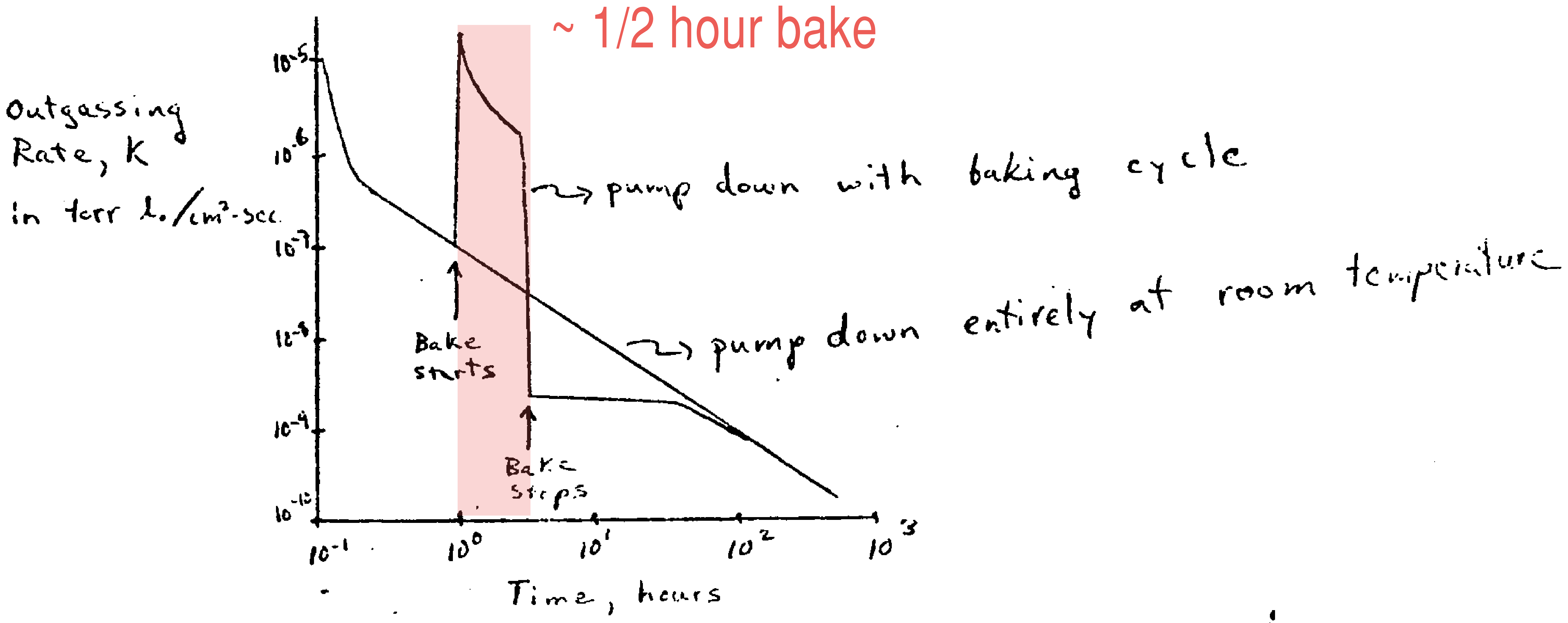


Figure 1. Outgassing Rate vs. Pumping Time, with and without Bake.

Overview of Week 3 (Option 2)

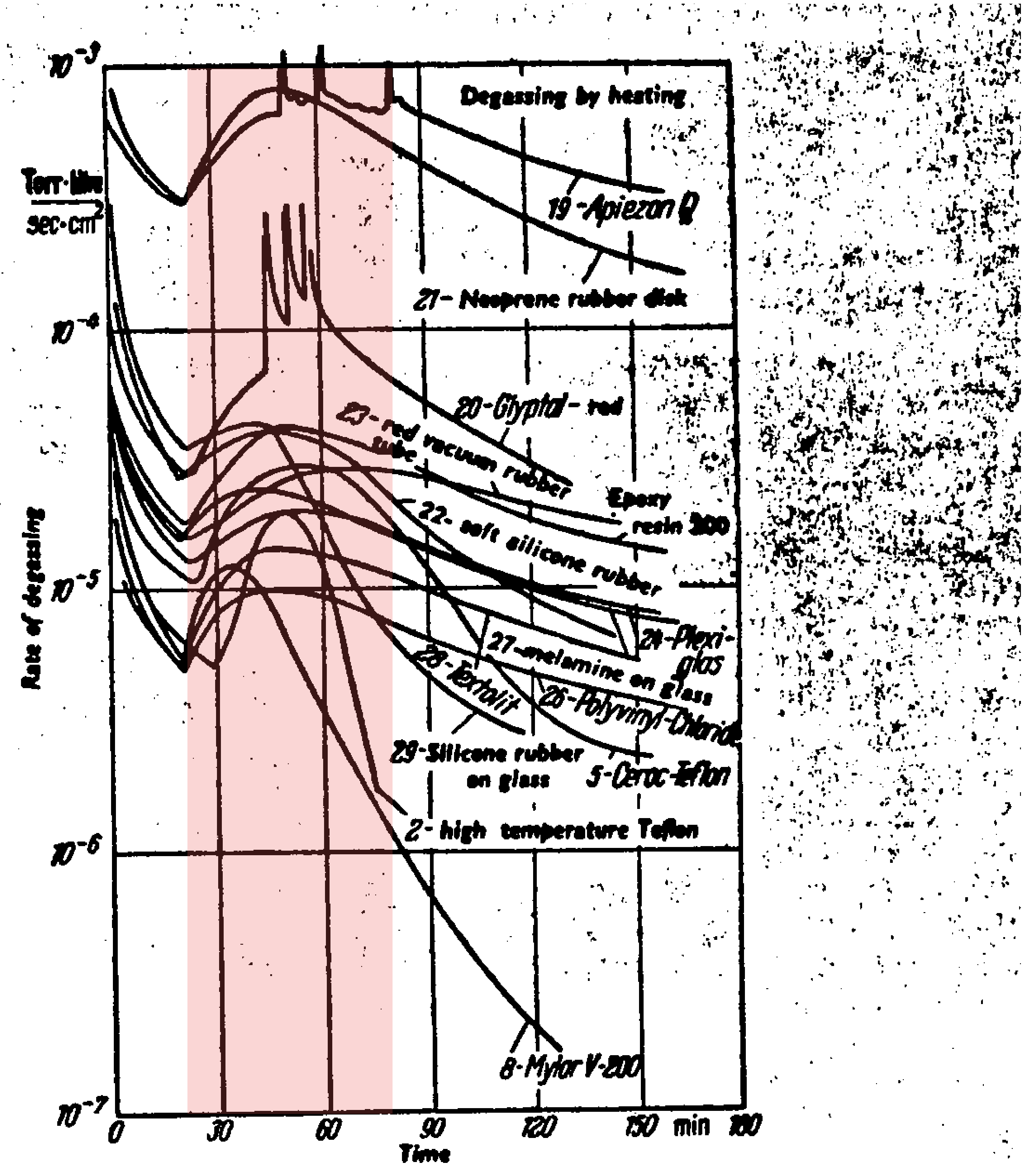


Fig. 2.4.12. Gas desorption during heating of plastic materials, which were exposed for 24 hrs to moist air (after SANTELER [21]).

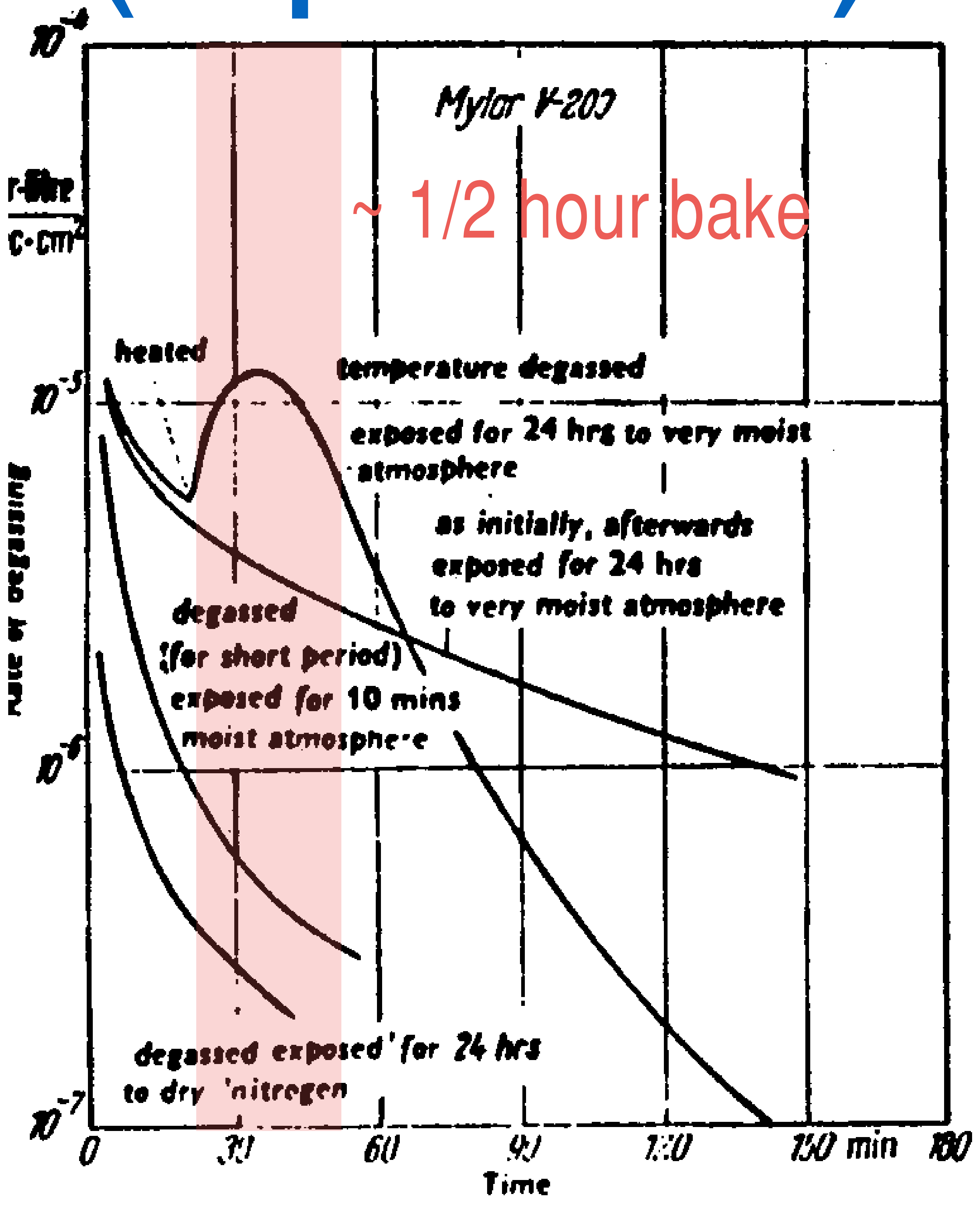
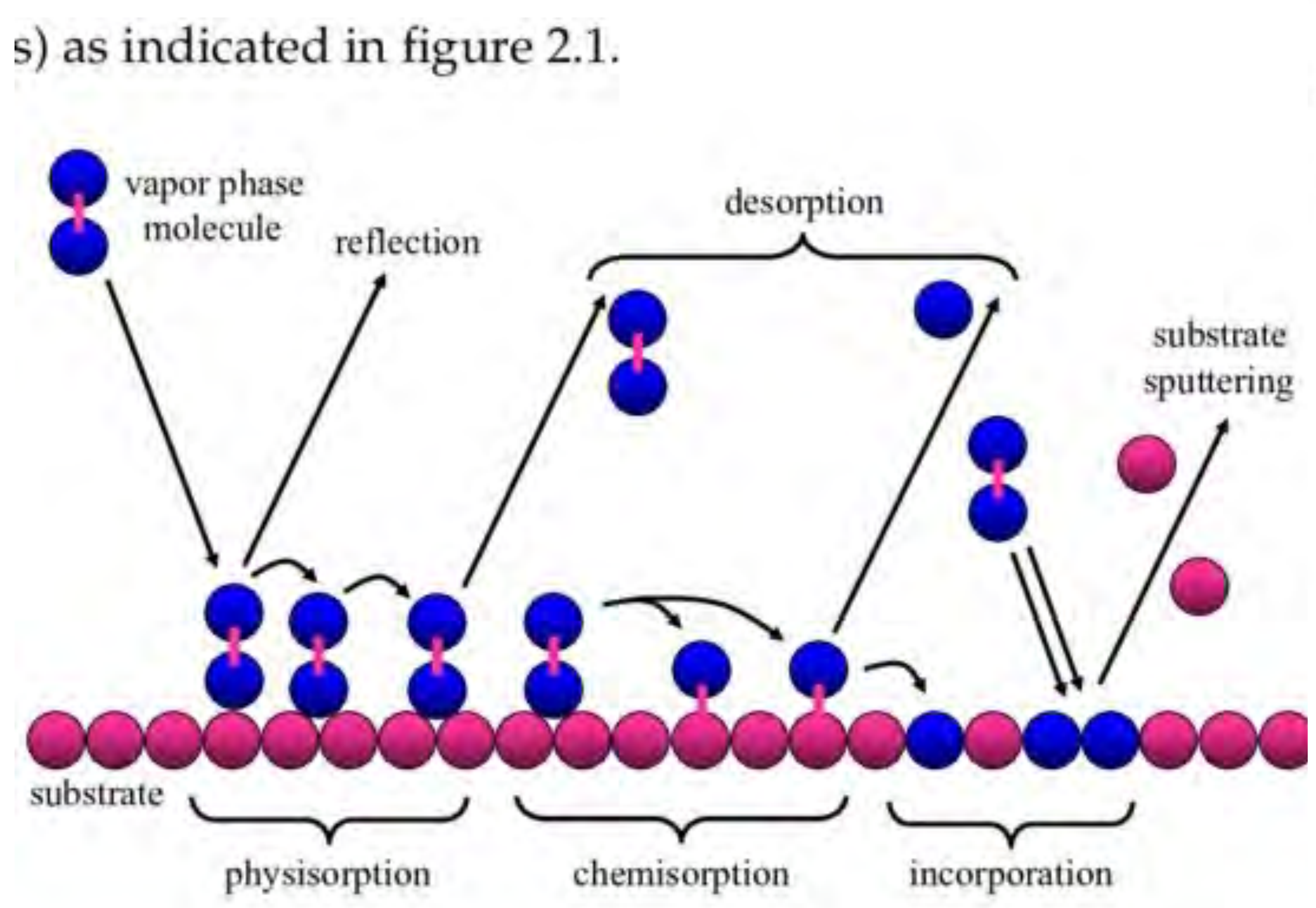
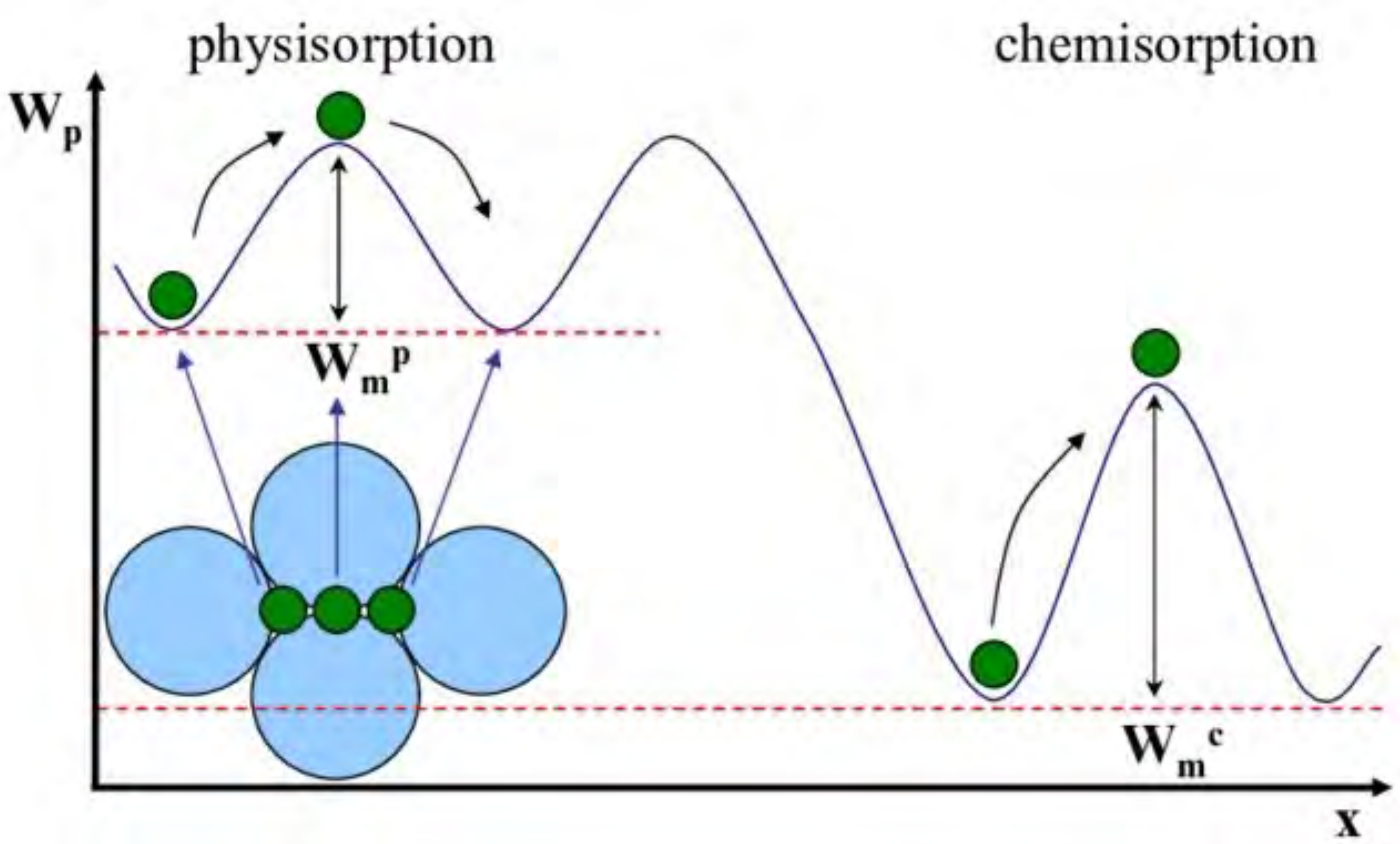


Fig. 2.4.10. Gas desorption of Mylar V-200 after various pre-treatments (after SANTELER [21]).

Binding Energy of Adsorbed Gas





Outgassing rate ~ Exp(kT/ΔW)
where ΔW is the wall "binding energy"

as T increases outgassing will
exponentially increase (at least initially)

From Prof. Andrei Mardare
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Week 3 Summary

- Option 1:
  - ➡ Measure the conductance of gas through pipes
  - ➡ $C \approx (P_1/P_2 - 1)/S$
- Option 2:
  - ➡ Measure outgassing of vacuum system as chamber temperature rises
  - ➡ Outgas: $G \sim \mathrm{Exp}[\ kT/\Delta W]$