Vacuum Science and Technology in Accelerators

Lecturers are the members of
ASTeC Vacuum Solutions Group:

Dr. Oleg Malyshev (Lectures 1,6)
Dr. Keith Middleman (Lectures 2,4)
Dr. Stuart Wilde (Lecture 3)
Dr. Reza Valizadeh (Lecture 5)

Jan-Feb 2023

Aims of the course

- To give a basic understanding of vacuum
  - Underlying physical principles
  - Some equations, little mathematics
  - Some limitations on what can be done
  - Vacuum instrumentation and components
- The role of vacuum, vacuum chamber surfaces and materials in accelerator design and operation
  - Why vacuum?
  - Vacuum chamber surface
  - Materials and their treatments
  - Constraints on vacuum design of accelerators

Lectures of the course

30th Jan 2021

- 10:30 Session 1 – Dr. Oleg Malyshev
  - The vacuum requirements of accelerators.
  - Introduction to vacuum design of accelerators.
- 11:45 Session 2 – Dr. Keith Middleman
  - The measurement of vacuum
  - The production of low pressures

6th Feb 2021

- 10:30 Session 3 – Dr. Stuart Wilde
  - Components and construction techniques
- 11:45 Session 4 – Dr. Keith Middleman
  - Material properties related to vacuum
  - Processing techniques for vacuum components and systems

13th Feb 2019

- 10:30 Session 5 – Dr. Reza Valizadeh
  - Surface science in accelerator R&D
- 11:45 Session 6 – Dr. Oleg Malyshev
  - Basic vacuum design of accelerators. Calculations to support the design. Examples and Revie.

Session 1

Part 1: Vacuum Requirements of Accelerators

Part 2: Basic Principles of Vacuum

Dr. Oleg B. Malyshev
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ASTeC Vacuum Solutions Group
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Aims of Part 1:
Vacuum Requirements of Accelerators

- To give a brief overview of vacuum in general
- To understand why different types of accelerators require different vacuum levels
- Specific vacuum problem in accelerators
- To take a preliminary look at the vacuum design process for accelerators

Introduction

- **Vacuum** (from Latin “*vacua*”) means **empty**
  - *In practice, gas density $n = 0$ particles/m^3 is an unreachable*
    - *There is always some number of particles in any volume:*
      - *Vacuum $\neq 0$*
      - *$n > 0$ particles/m^3*
    - *This also means that everybody who needs a FULL VACUUM is a dreamer!*

- In the gas dynamics, Vacuum is the gas state when **P < 1 bar**
  - *as soon as gas from a closed volume is pumped out all that remains is called ‘vacuum’*
  - *this is a realistic approach and a real science*

- Vacuum is *a problem* for many applications and researchers and it is ***a subject*** of ***Vacuum Science and Technology.***

Vacuum Science and Technology

"So, if vacuum science is the science about nothing, what does vacuum scientists know?"

- Where does the gas particles come from?
  - Leaks and leak detection, outgassing, induced desorption...
- How to suppress the gas sources?
  - mechanically, choice of materials, cleaning, baking, etc...
- How to remove the gas out of vacuum system?
  - Different types of pumps based on very different physics principles.
- How to measure vacuum?
  - Different types of gauges for different pressure ranges, RGAs, indirect (non-gauge) measurements…
- How to design a vacuum system
  - Gas dynamics, surface physics and chemistry, material properties, a lot of measurements, a lot of engineering.
- How to operate vacuum systems
  - Performance (specification), Economics.

A reminder!

- For most purposes vacuum is just a tool or a required condition
- Most users would prefer not to have to bother with it
- The accelerator scientists who determine the properties of the next generation of machines would like the vacuum scientists and engineers to design a vacuum system where
  - The pressure is zero
  - The vacuum pumps and gauges take up no space
  - The cost is trivial
  - But… it’s too far from that all!

Vacuum

- There’s nothing in it!

	Particles m^{-3}
Atmosphere	2.5×10^{25}
Vacuum Cleaner	2×10^{25}
Freeze dryer	10^{22}
Light bulb	10^{20}
Thermos flask	10^{19}
TV Tube	10^{14}
Low earth orbit (300km)	10^{14}
Diamond LS	10^{13}
Surface of Moon	10^{11}
Interstellar space	10^{5}

Vacuum Units

- SI pressure Unit – Pascal (1 N·m^{-2})
  - Pa is used by all metrology labs, in Asia
  - In Europe – mbar (100 Pa) is more common
  - In USA/Asia – Torr (133.322 Pa)

- Atmosphere = 1.01325 bar = 760 Torr
- bar = 10^5 Pa = 10^3 mbar $\cong$ 750 Torr = 0.98692 atm.

- Gas density units - particles/m^3

$$P = nk_BT$$

P – pressure, n – gas density (number gas density),

k_B – Boltzmann coefficient, T – temperature

Accelerators

- Particle accelerators come in many shapes and sizes:
  - Small LINACs
  - Medical Cyclotrons
  - Electrostatic
  - Synchrotrons
    - Leptons
    - Hadrons
  - Storage Rings
    - Synchrotron Light Sources
  - Colliders
    - LHC, Tevatron, KEK-B, DAΦNE
    - ILC, CLIC

Accelerators

- All need Vacuum to a greater or lesser extent e.g.
  - 10^{-5} – 10^{-6} mbar in small linacs, Van de Graafs
  - 10^{-7} – 10^{-8} mbar in proton synchrotrons
  - 10^{-9} – 10^{-10} mbar in synchrotron light sources
  - 10^{-11} – 10^{-12} mbar in antiproton accumulation rings
  - $< 10^{-12}$ mbar in heavy ion rings and in Ga-Ar photocathode vacuum chambers

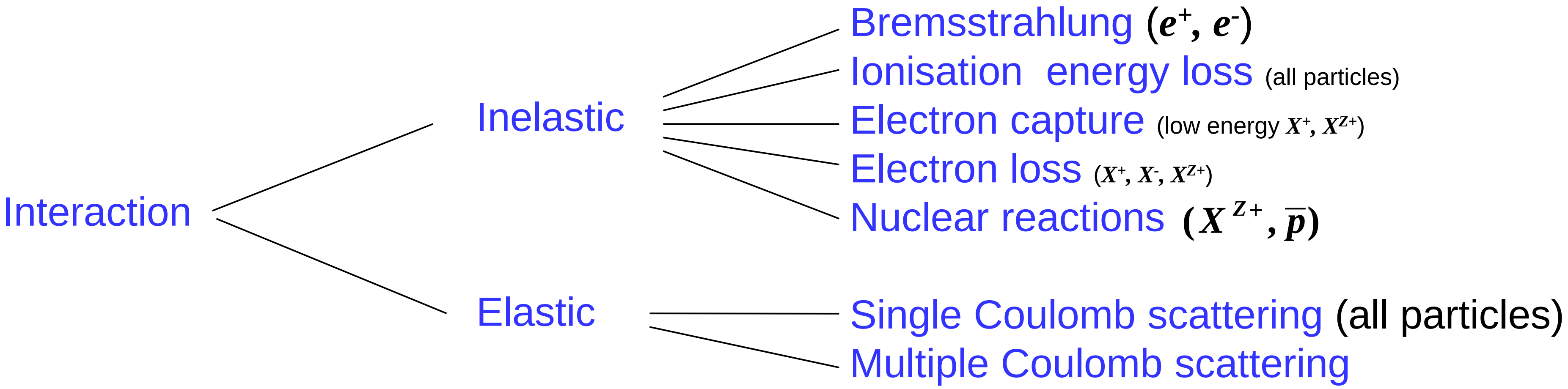
Accelerators

- The main reason for vacuum is beam-gas interaction (e.g. scattering) leading to a beam quality degradation
  - Single pass machines
    - Increases beam size (emittance)
    - Increases radiation hazard
    - Encourages recombination
  - Stored beam machines
    - Increases beam size
    - Reduces beam lifetime
    - Increases radiation hazard

Particle-gas interactions

- Depend on number density and nature of gas molecule (and particles)
- Two types
  - Elastic
  - Inelastic
- Scatter particles out of beam
  - Hit vacuum chamber walls or other obstructions
    - loss of particles, radiation hazard
  - If not lost, increase beam size
- Cause residual gas ionisation
  - Ion and electron induced beam instabilities

Interaction between the Beam and Residual Gas Molecules



Interaction

Inelastic

- Bremsstrahlung (e^+, e^-)
- Ionisation energy loss (all particles)
- Electron capture (low energy X^+, X^{Z+})
- Electron loss (X^+, X^-, X^{Z+})
- Nuclear reactions $(X^{Z+}, \bar{p})$

Elastic

- Single Coulomb scattering (all particles)
- Multiple Coulomb scattering

The beam current I decays with time t as: $I = I_0 \exp(-t/\tau)$

where τ is the total beam lifetime given by the beam lifetime τ_{beam} due to different Quantum, Touschek, particle lifetime, etc.,

$$\tau^{-1} = \tau_{beam}{}^{-1} + \tau_{gas}{}^{-1}$$

and gas lifetime defined as: $\tau_{gas} = 1/v\sigma n$

☞ i.e. there must be: $\tau_{gas} > \tau_{beam}$

Main criteria for 'good vacuum' for the accelerator

- $\tau_{gas} > \tau_{beam}$ *(for storage rings)*
- The beam loss rate due to a beam-gas interaction is tolerable (linacs)
- The beam properties (ex.: emittance) aren't affected by a beam-gas interaction
- The detector operation in a collider is not affected by beam-gas interactions
- Residual radiation of vacuum chamber and equipment in an accelerator tunnel due to a beam-gas interaction is tolerable
- Radiation safety criteria during accelerator operation is met

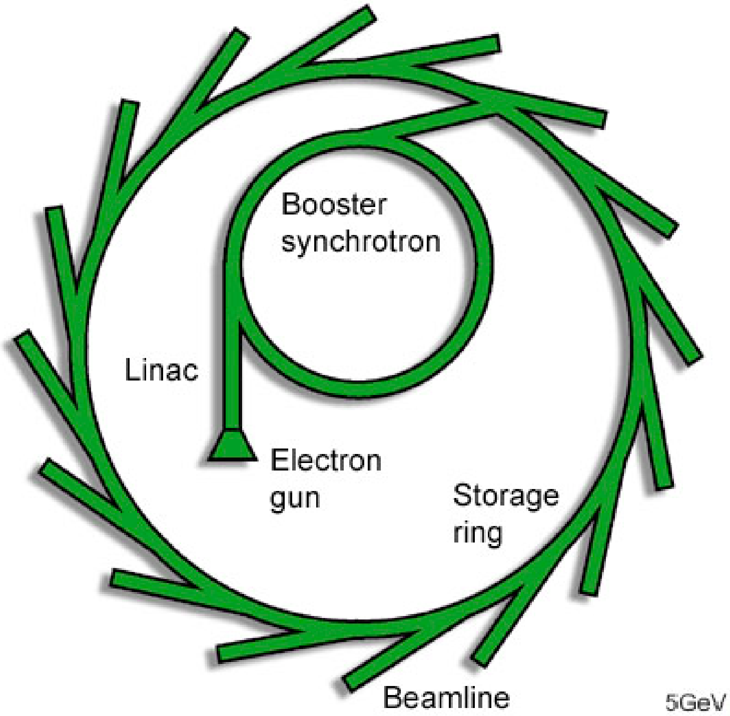
Accelerator Vacuum Specification

- From such considerations, the accelerator physicist will calculate the ***permissible beam-gas interaction rate*** to give the desired performance of the accelerator
- This requires a ***basic design*** (lattice and apertures)
- The vacuum specification will then (ideally) be
  - An average and peak pressure (or gas density) or a set of ***number densities*** of likely gas species at all points (sectors, sections) around (or along) the machine
  - Specify ***when*** these spec. should be reached in respect to a machine lifetime (ex. after 100 A·hr, after 1st year of operation, etc.)

Accelerator Vacuum Design

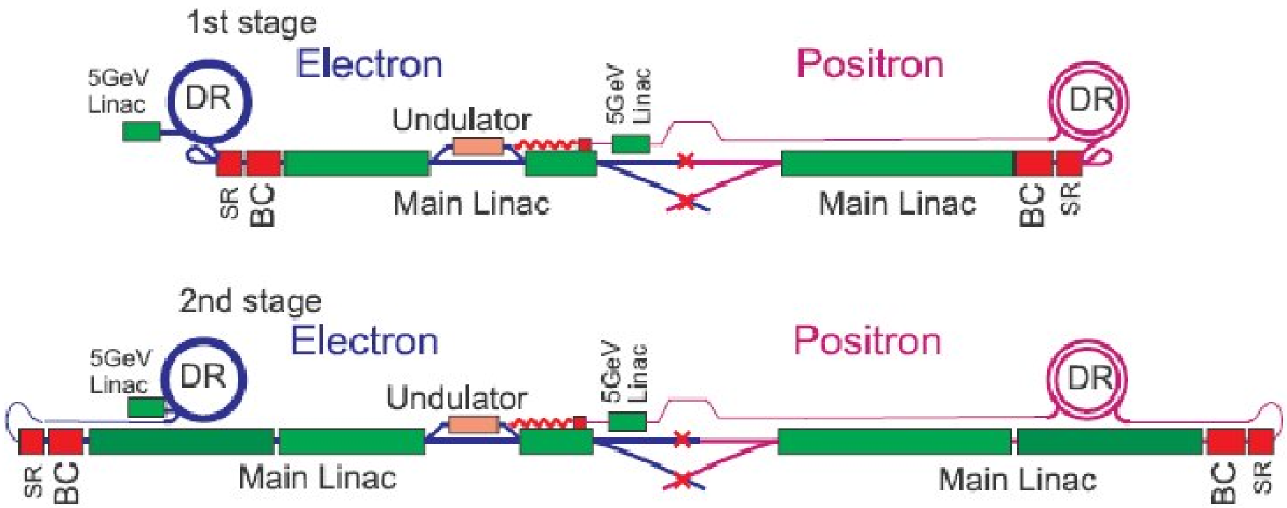
- The task of the vacuum scientist/engineer is then to
    - design the containment system and any specialist mechanical items (e.g. scrapers, shutters, beam diagnostic devices)
    - calculate the size, number, position and types of the vacuum pumps necessary to achieve the specified number densities (or pressures)
        - for this a reasonable mechanical design/layout is required
    - determine the necessary vacuum diagnostics
    - define the required treatments of vacuum chamber and its component

Design



Storage ring

Linear collider

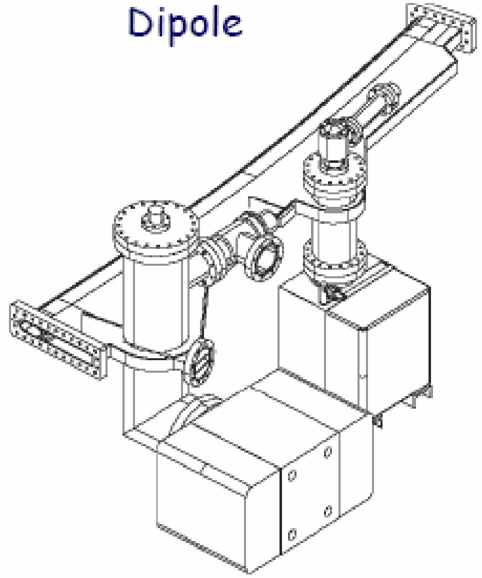


Why is meeting a vacuum specification not a simple process?

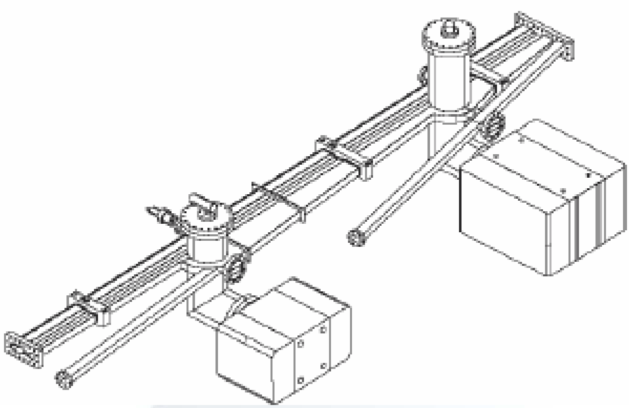
- Some things are not well defined
  - Pumping speeds
  - Outgassing/desorption properties of materials
  - Vacuum chamber shape
  - Accuracy of vacuum diagnostics
- It is difficult to get enough pumping to where it is required
- There are often conflicting requirements between different disciplines, e.g. apertures, wakefield.
- Accurate vacuum calculations are difficult and time consuming
- A good technical solution may be too expensive
- Several design iterations are usually required to reach a satisfactory compromise

Examples of some vacuum chambers and their cross sections

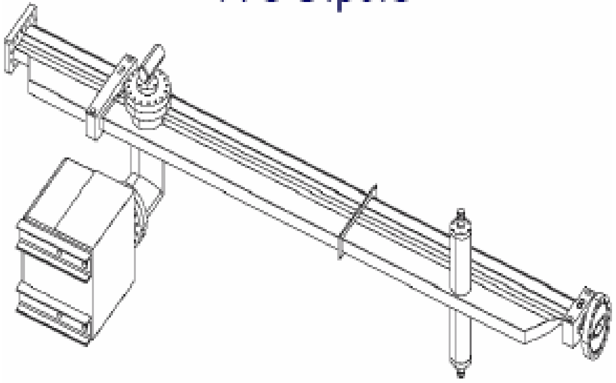
Dipole

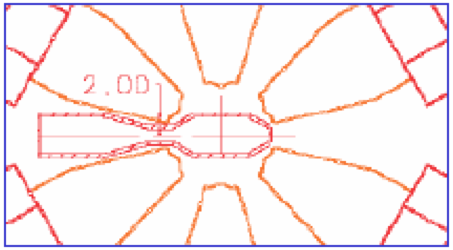


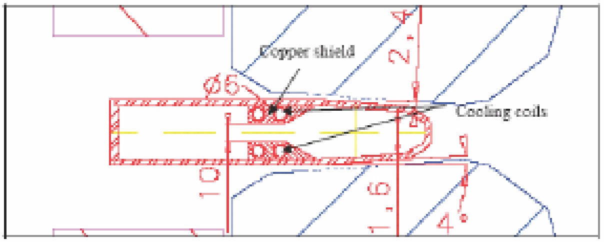
Post Dipole

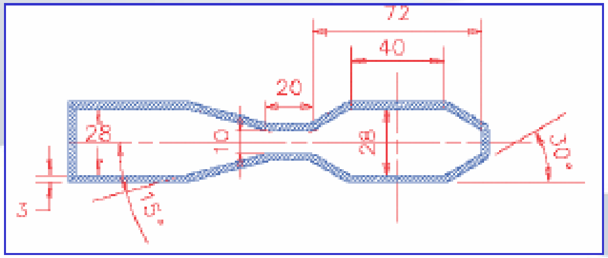


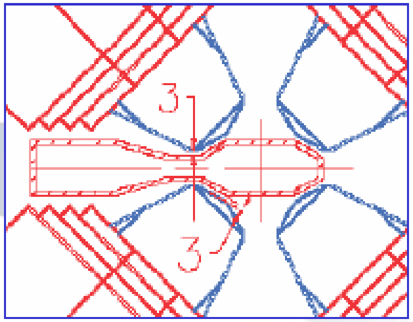
Pre Dipole



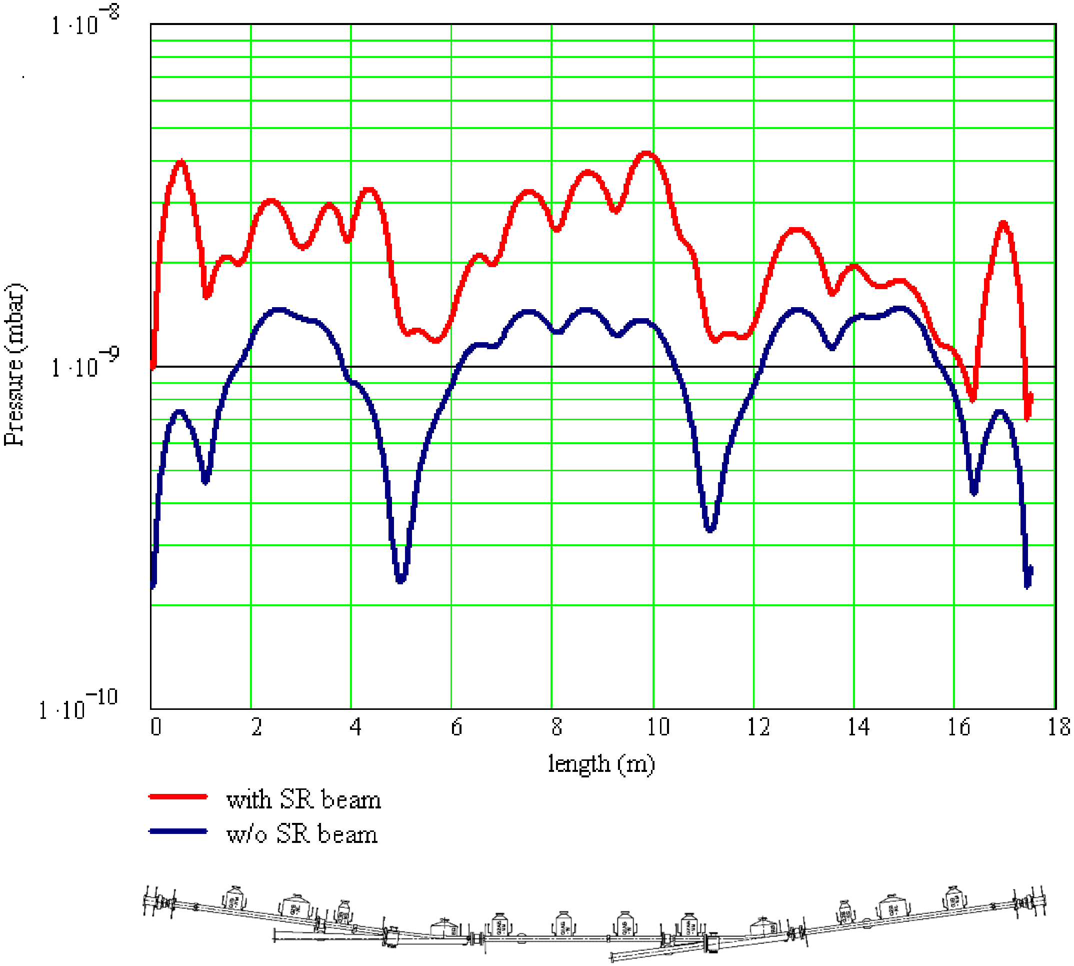








An example: Diamond pressure profile along the arc after 100 A·hrs beam conditioning



Average pressure

without a beam:

$\langle P_t \rangle = 1\cdot10^{-9}$ mbar

due to SR photons only

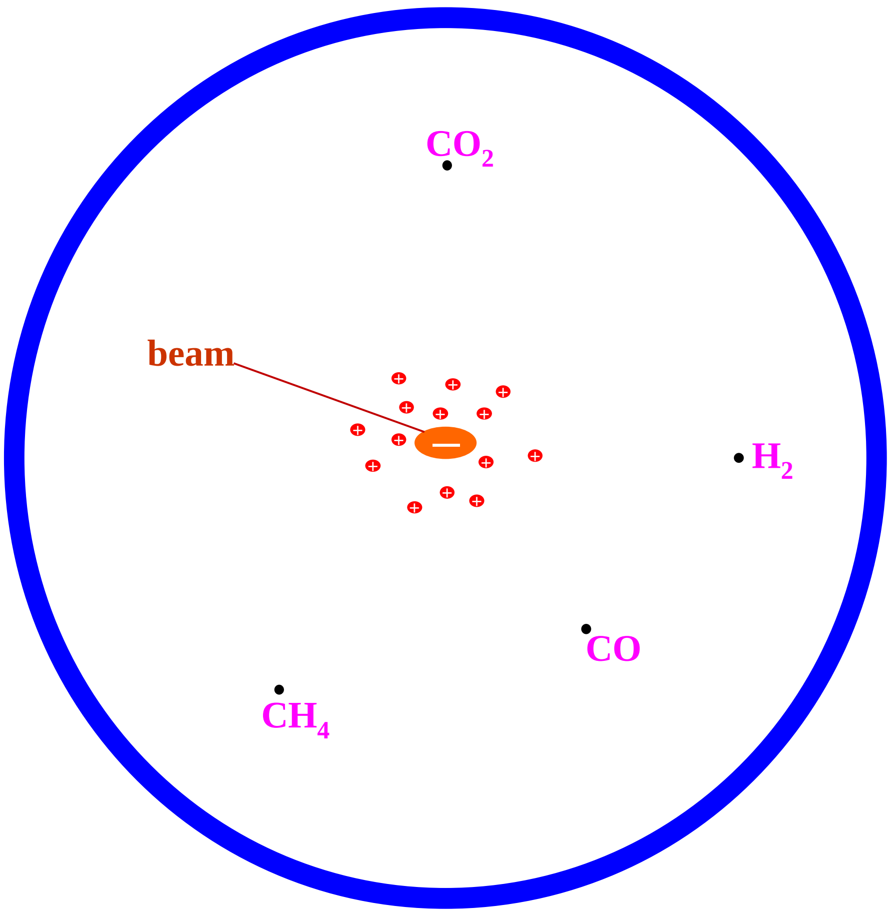
$\langle P_\gamma \rangle = 1\cdot10^{-9}$ mbar

Sum (i.e with a beam):

$\langle P_{din} \rangle = \langle P_t \rangle + \langle P_\gamma \rangle =$

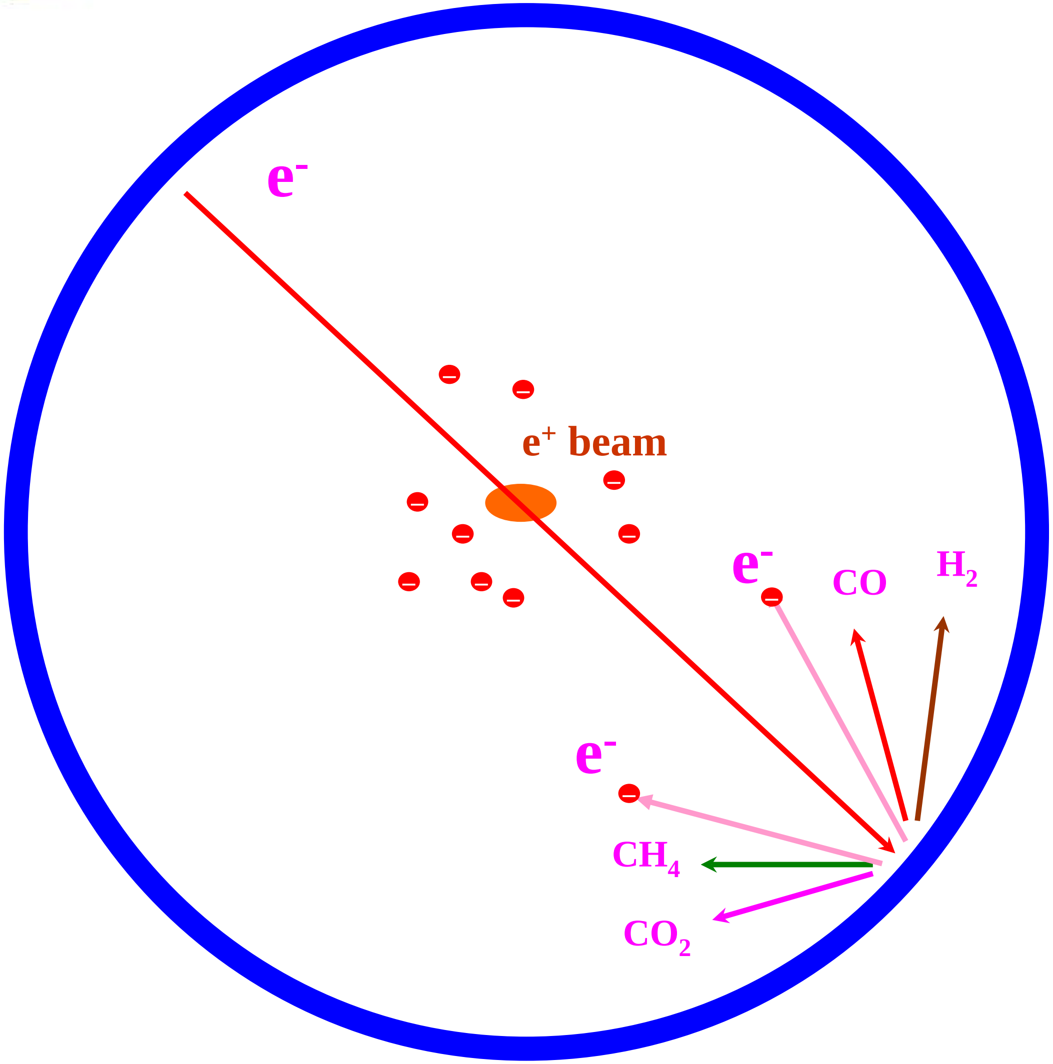
$= 2\cdot10^{-9}$ mbar

Ion induced instability with the negatively charged beams



- Residual gas molecules are ionised by the beam
- The positively charged ions build up an ion cloud along the negatively charged beam path
- The ions cause the ion induced beam instability
- Mitigation:
  - Better pumping system
  - Ion collectors

Electron cloud with the positively charged beams

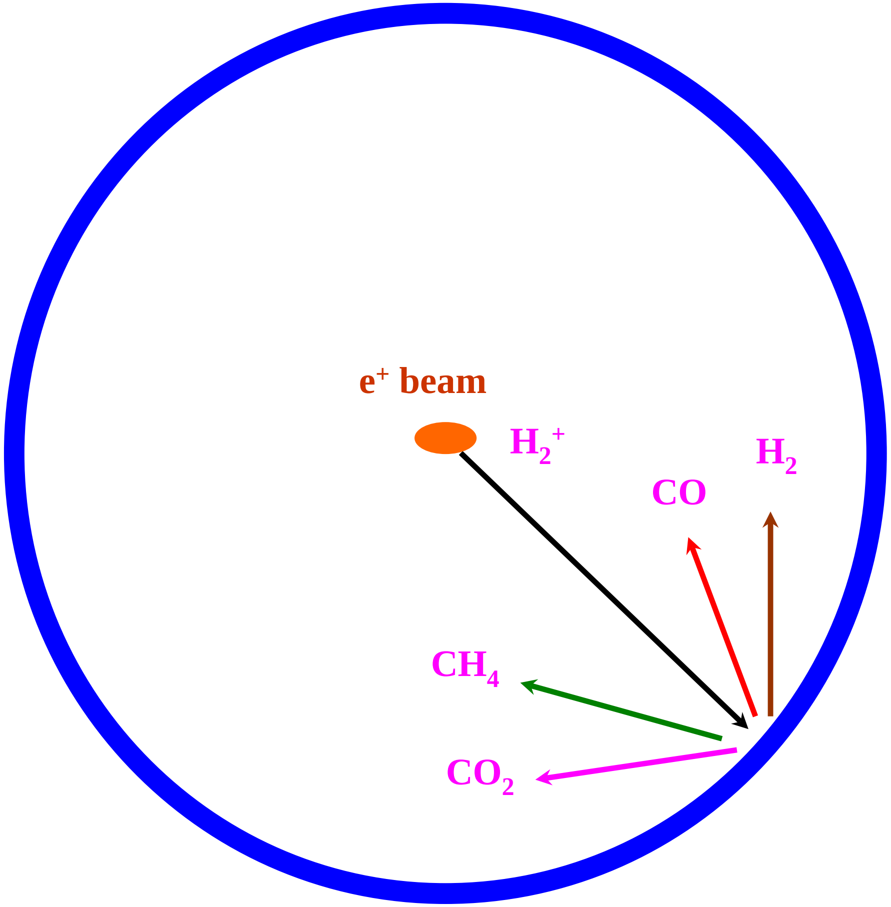


1. Electrons appear in vacuum chamber due to photoemission and electron from a beam induced gas ionisation
2. Electrons are accelerated by the beam charge and drift between bunches
3. These electrons may strike the vacuum chamber wall causing
   - Secondary electrons
   - Electron stimulated gas desorption
4. These electrons build up an electron cloud that cause a beam emittance 'blow-up'

Sources of electrons and their mitigation techniques

- Photo-electrons
  - Geometrical: antechamber or other means of reduction or localisation of direct and reflected photons
  - Surface treatment, conditioning, thin film coatings
- Secondary electrons
  - Passive means:
    - Low SEY coatings (ex.: NEG, TiN, a-C, *etc*.)
    - Grooves on vacuum chamber
    - Laser treated surfaces (LASE)
  - Active means:
    - Biased electrodes
    - Solenoidal magnetic field
    - Beam train parameters (charge and bunch spacing)
- Gas ionisation
  - Surface treatment and conditioning
  - Low outgassing coating
  - Better pumping

Ion induced pressure instability with the positively charged beams



$$n = \frac{Q}{S_{eff} - \chi \frac{\sigma I}{e}}$$

where

Q = gas desorption,

S_{eff} = effective pumping speed,

χ = ion induced desorption yield

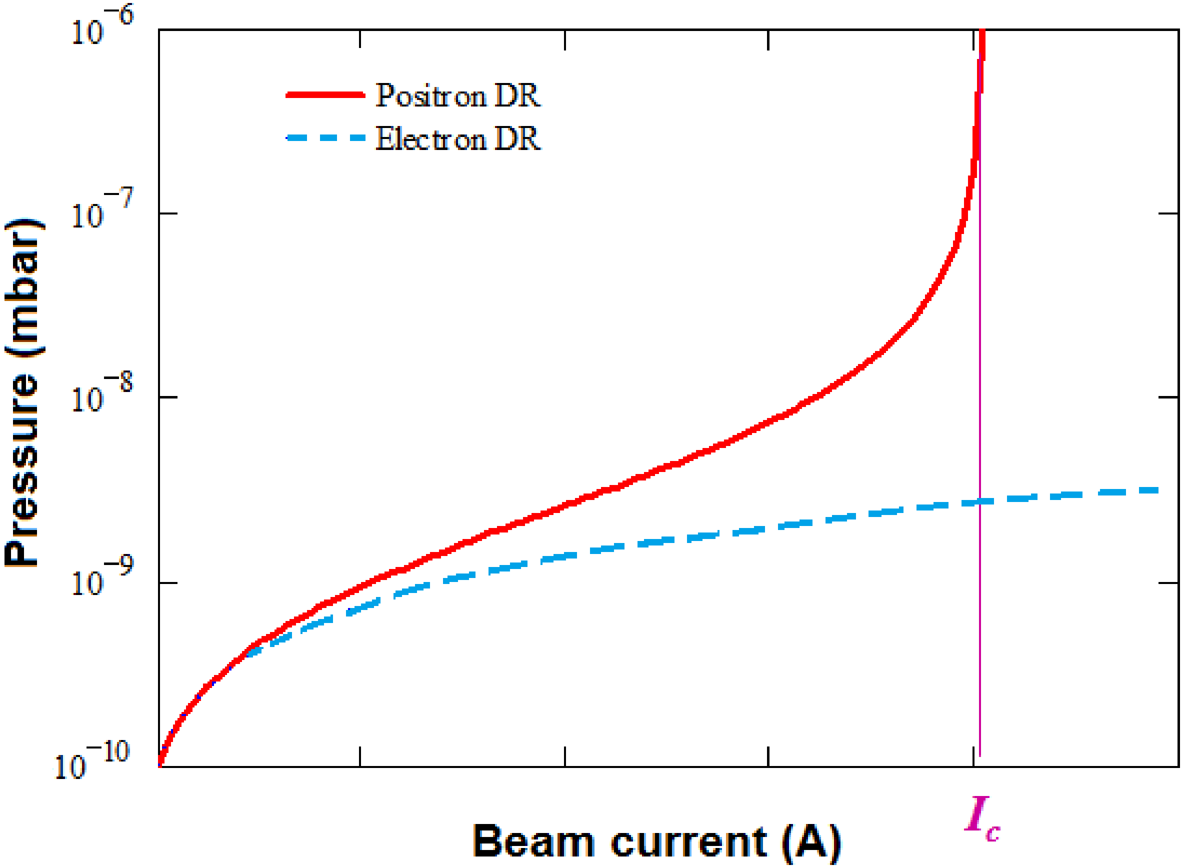
σ = ionisation cross section,

I = beam current.

$$\chi = f\left(E_{ion}, M_{ion}, material, bakeout, \ldots\right)$$

$$E_{ion} = f\left(N_{bunch}, \tau, T, \sigma_x, \sigma_y, \ldots\right)$$

Critical current



Critical current, I_c, is a current when pressure (or gas density) increases dramatically.

Mathematically, if

$$P = \frac{Q}{S_{eff} - \chi \frac{\sigma I}{e}}$$

$$\text{when } S_{eff} > \chi \frac{\sigma I}{e}$$

$$\text{Hence } I < I_c,$$

$$\text{where } I_c = \frac{S_{eff} e}{\chi \sigma I}$$

Pressure instability thresholds:

What can be calculated for given beam parameters and vacuum chamber geometry:

- I_c – critical current
  - Required: $I \ll I_c$, where I is a maximum beam current
- L_c – critical length between pumps
  - Required: $L \ll L_c$, where L is an actual distance between pumps
- $\mathrm{S_c}$ – critical pumping speed
  - Required: $S \gg S_c$, where S is an effective pumping speed at this location

Session 1
Part 2

Basic Principles of Vacuum

Aims of Part 2:
Basic Principles of Vacuum

- To present some of the results of the kinetic theory of gases and to understand how they affect our thinking about vacuum
- To understand the differences between gas flow regimes
- To understand why conductance is an important concept in vacuum

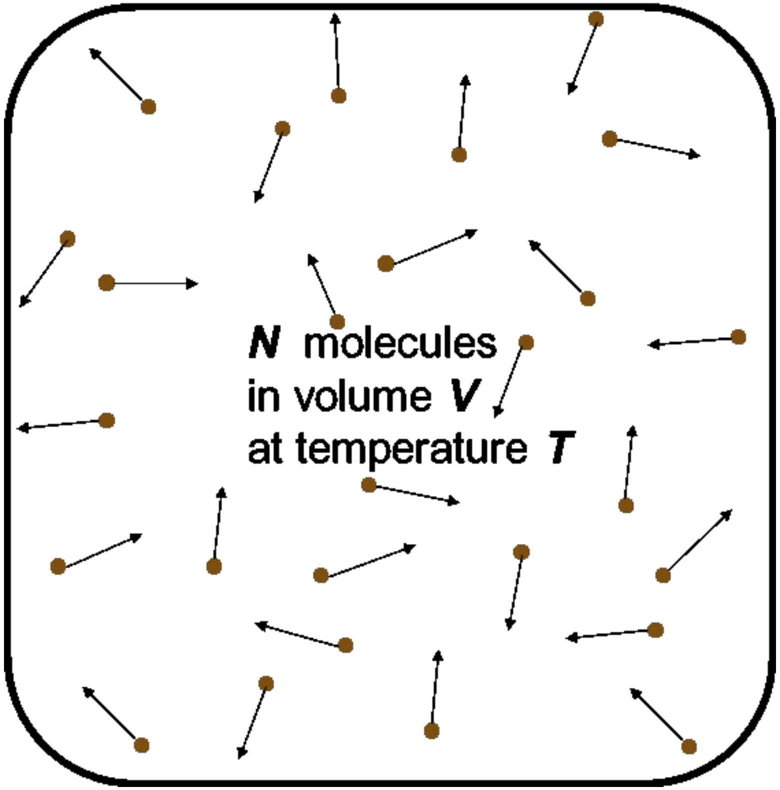
Gas in a closed volume

- Consider gas as collection of independent small spheres in random motion, with average velocity $\bar{v}$
- All collisions are elastic

Volume of box = V

Number of molecules = N

Number density $n = N/V$



Amount of gas

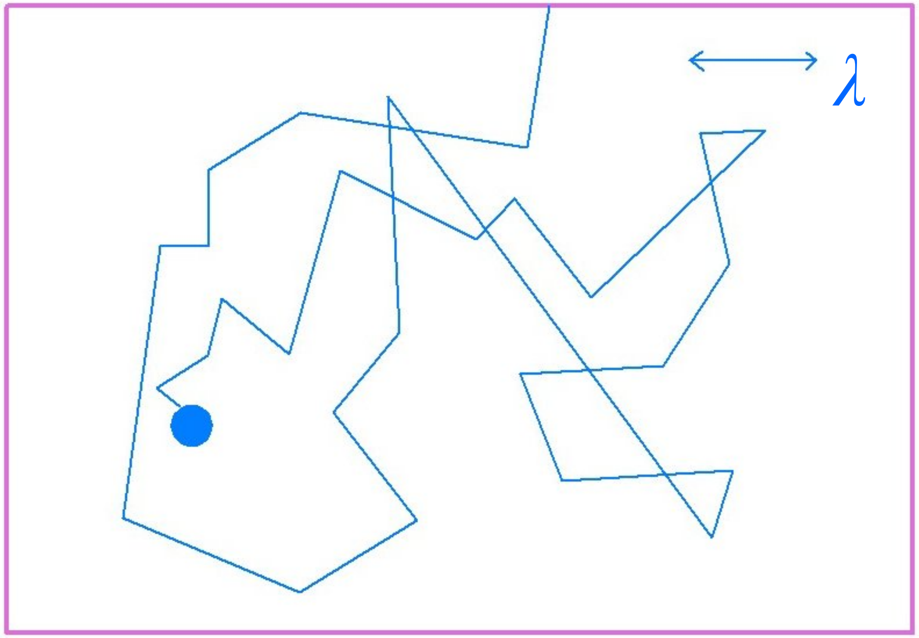
Can be measured

- in units of mass [kg] or density [kg/m^3]
- In [moles]: $$\nu[mole] = \frac{N}{N_A}$$
  - where $N_A = 6.02214\times10^{23}$ is the Avogadro constant is the number of constituent particles (atoms or molecules) that are contained in the amount of substance given by one **mole**.
- In [mbar·l] in vacuum technology: $$Q[mbar\cdot l] = PV = N k_B T$$
  - where $k_B = 1.38065\times10^{-23}$ J/K = 1.38065×10^{-23} Pa·m^3/K is the Boltzmann constant

Kinetic Theory

- Molecules follow a random walk
- Mean free path λ

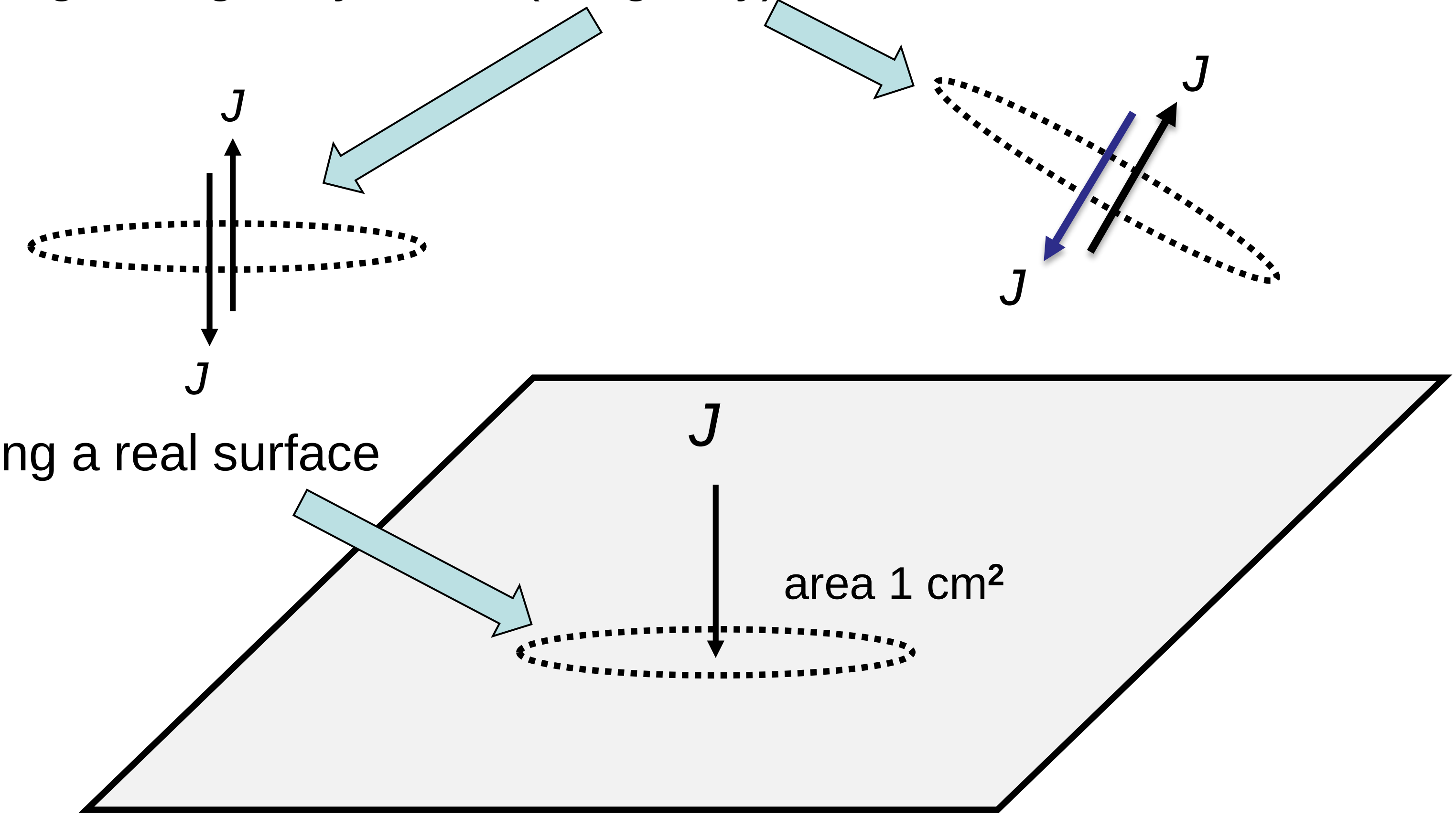
Pressure (mbar)	Mean free path (m)
10^{3}	6×10^{-8}
1	6×10^{-5}
10^{-3}	6×10^{-2}
10^{-6}	6
10^{-10}	6×10^{5}



Impingement rate, *J*

The pressure, *P*, exerted on the walls of the vessel depends on the molecular impingement rate or flux, *J* [molecules/(cm^2·s)]

- Passing through any virtual (imaginary) surface



- Hitting a real surface

Velocity of gas molecules

- Molecular velocity distribution (Maxwell-Boltzmann distribution):
  - Most probable velocity, v_{mp} :

$$v_{mp} = \sqrt{\frac{2RT}{M_m}} = \sqrt{\frac{2k_BT}{m_m}}$$

  - An average of absolute value of the velocity vector (also known as mean speed), $\bar{v}$:

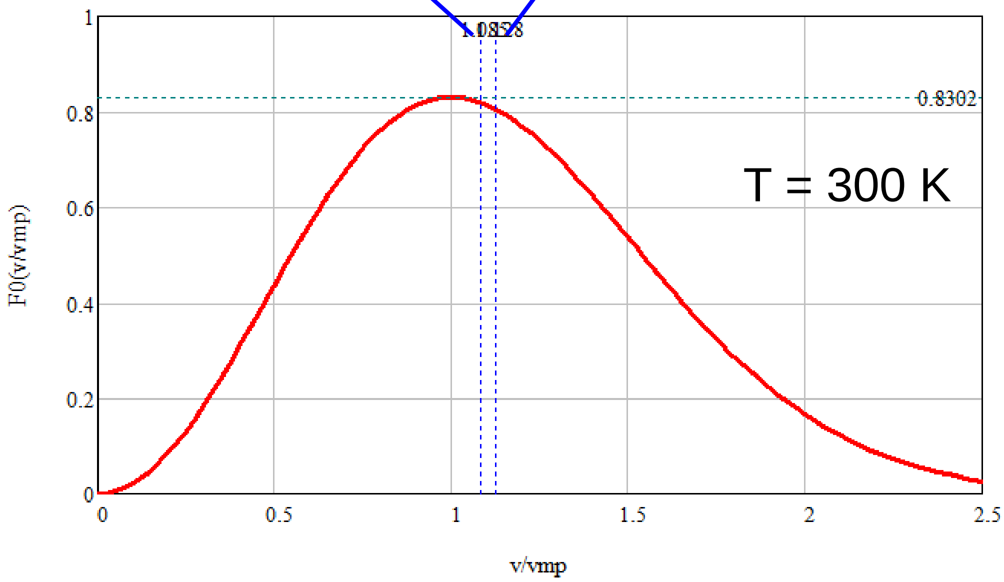
$$\bar{v} = \sqrt{\frac{8RT}{\pi M_m}} = \sqrt{\frac{8k_BT}{\pi m_m}}$$

  - The root-mean-square velocity, v_{rms}, is defined as:

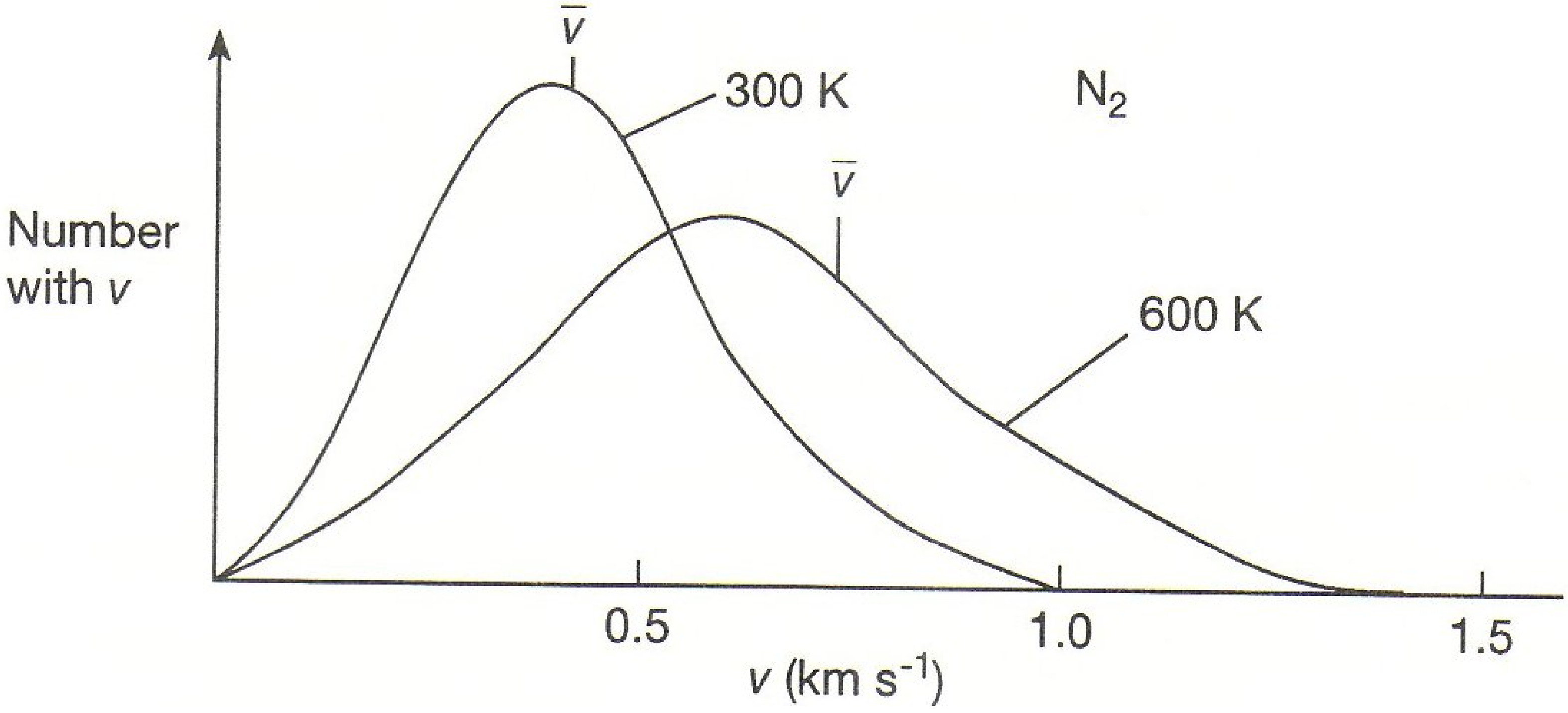
$$v_{rms} = \sqrt{\frac{3RT}{M_m}} = \sqrt{\frac{3k_BT}{m_m}}$$

$$F_0\left(\frac{v}{v_{mp}}\right) = \frac{4}{\sqrt{\pi}}\frac{v^2}{v_{mp}^2}\exp\left(-\frac{v^2}{v_{mp}^2}\right)$$

$$\frac{\bar{v}}{v_{mp}} = 1.085 \qquad \frac{v_{rms}}{v_{mp}} = 1.128$$



Maxwell-Boltzmann Distribution at different temperatures



Some results from Kinetic Theory

Average kinetic energy	$\frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$
Average velocity	$\bar{v} = \sqrt{\frac{8kT}{\pi m}} = \sqrt{\frac{8RT}{\pi M}} = 145\sqrt{\frac{T}{M}}$
Pressure	$P = nkT$
Mean free path	$\lambda = \frac{1}{\sqrt{2}\pi d^2 n}$
Impingement Rate	$J = \frac{p}{\sqrt{2\pi mkT}} = \frac{pN_A}{\sqrt{2\pi MRT}}$

Note
the presence
of *n* in all three

The Gas Laws

Boyle's Law $pV = NkT = n_M RT$

Avogadro's Number 6.02 x 10^{23}

$V_M = 22.4\ l$ at 273 *K* and 1.103 *Pa*

Dalton's Law $P = \sum_i P_i$

A Useful Exercise

From the equation for impingement rate, if we assume that every gas molecule which impinges on a surface sticks, prove that the time, τ, to form *a <u>monolayer of gas</u>* at a pressure *P* (mbar) on a surface (i.e. where there is one gas atom for each atom in the surface) is given by

$$\tau(s) \approx \frac{10^{-6}}{P(mbar)}$$

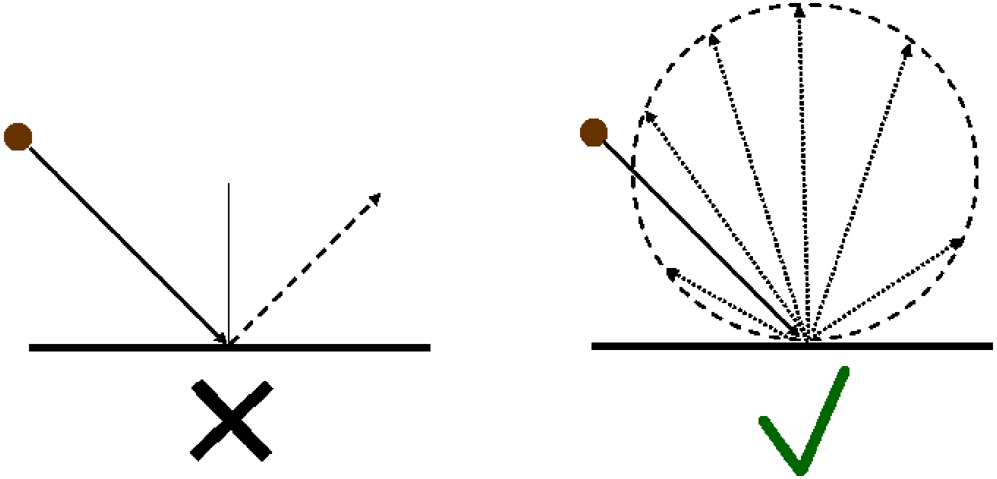
⇨

$$\text{For } P = 10^{-9}\ mbar$$

$$\tau \approx 10^{3}\ s$$

Interaction with a wall

- Molecules hitting rough technical surfaces are
  - adsorbed at the surface for a very short time (sojourn time),
  - fully thermalised with a wall (this is called as a complete accommodation),
  - then desorbed with diffuse (cosine) low
- Practically, this means that a particle can be reflected to any direction independent of its velocity before the collision with a surface. Such an interaction is called as the complete accommodation
- Mirror reflections could be considered as negligible, i.e. molecules do NOT rebound like tiny snooker balls



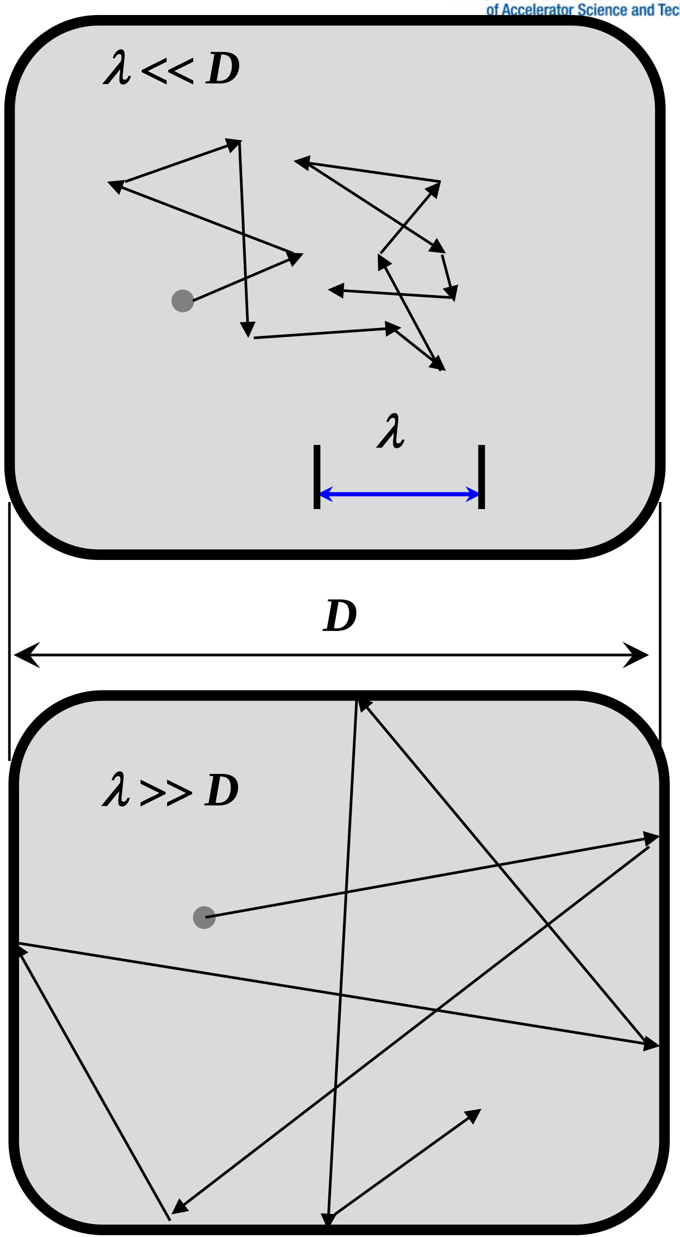
In many practical applications the diffuse scattering is well justified and provides reliable results

Gas Flow

- There are several so-called gas flow regimes
  - Continuum flow
    - Fluid flow
    - Short mean free path
    - Molecule-molecule collisions are dominant
  - Transitional flow
    - Molecule-molecule collisions and molecule-wall collisions are equally important for the gas flow
    - Gas flow modelling is the most challenging
  - Molecular flow
    - Long mean free path
    - No molecule-molecule collisions

Gas flow regimes

- Viscous gas flow regime
  - molecule-molecule collisions dominate behaviour
  - $\lambda << D$ or $Kn < 0.01$
- Transitional gas flow regime
  - molecule-molecule collisions and molecule-wall collisions are equally important for the gas flow
  - $\lambda \sim D$ or $0.01 < Kn < 10$
- Free molecular gas flow regime
  - molecule-molecule collisions dominate behaviour
  - $\lambda >> D$ or $Kn > 10$
- Knudsen number, *Kn* defined as $Kn = \lambda / D$
  - Kn = mean free path at prevailing pressure / typical dimension



Classification of Vacuum Ranges: ISO 3529-1:2019

For convenience, ‘to distinguish between various ranges or degrees of vacuum according to certain pressure intervals’, the ranges of vacuum are defined

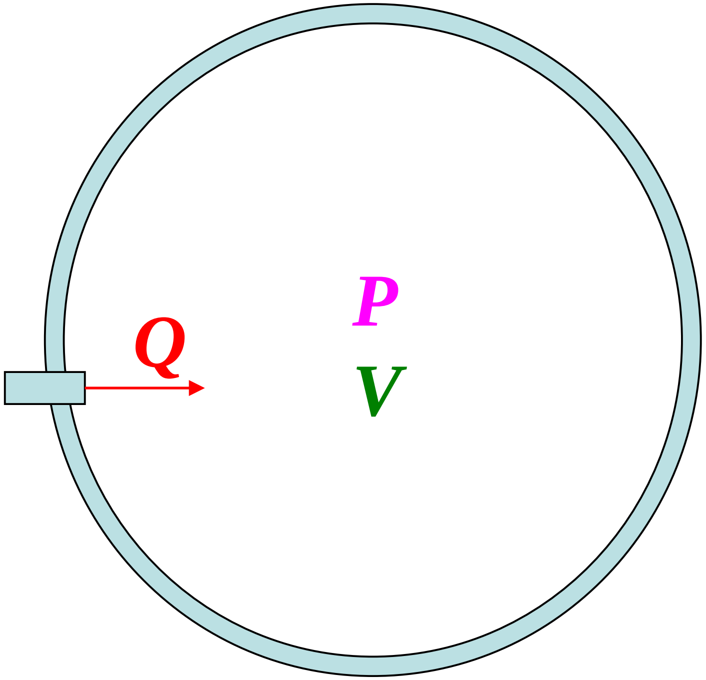
Vacuum ranges	Pressure	The reasoning for the definition of the ranges is as follows (typical circumstances):
low (rough) vacuum	Prevailing atmospheric pressure (31-110 kPa) to 100 Pa	Pressure can be achieved by simple materials (e.g. regular steel) and positive displacement vacuum pumps; viscous flow regime for gases
medium (fine) vacuum	<100 Pa to 0.1 Pa	Pressure can be achieved by elaborate materials (e.g. stainless steel) and positive displacement vacuum pumps; transitional flow regime for gases
high vacuum (HV)	<0.1 Pa to 10^{-6} Pa	Pressure can be achieved by elaborate materials (e.g. stainless steel), elastomer sealings and high vacuum pumps; molecular flow regime for gases
ultra-high vacuum (UHV)	<10^{-6} Pa to 10^{-9} Pa	Pressure can be achieved by elaborate materials (e.g. low-carbon stainless steel), metal sealings, special surface preparations and cleaning, bake-out and high vacuum pumps; molecular flow regime for gases
extremely high vacuum (XHV)	below 10^{-9} Pa	Pressure can be achieved by sophisticated materials (e.g. vacuum fired low-carbon stainless steel, aluminium, copper-beryllium, titanium), metal sealings, special surface preparations and cleaning, bake-out and additional getter pumps; molecular flow regime for gases

Throughput (Gas Load)

- Gas Load or Throughput – rate gas evolves within or enters the volume)

- Pressure ***P*** in a vacuum vessel is defined by the total gas load, ***Q*,** and total Volume, ***V***.

In the case of a simple vacuum chamber it is :



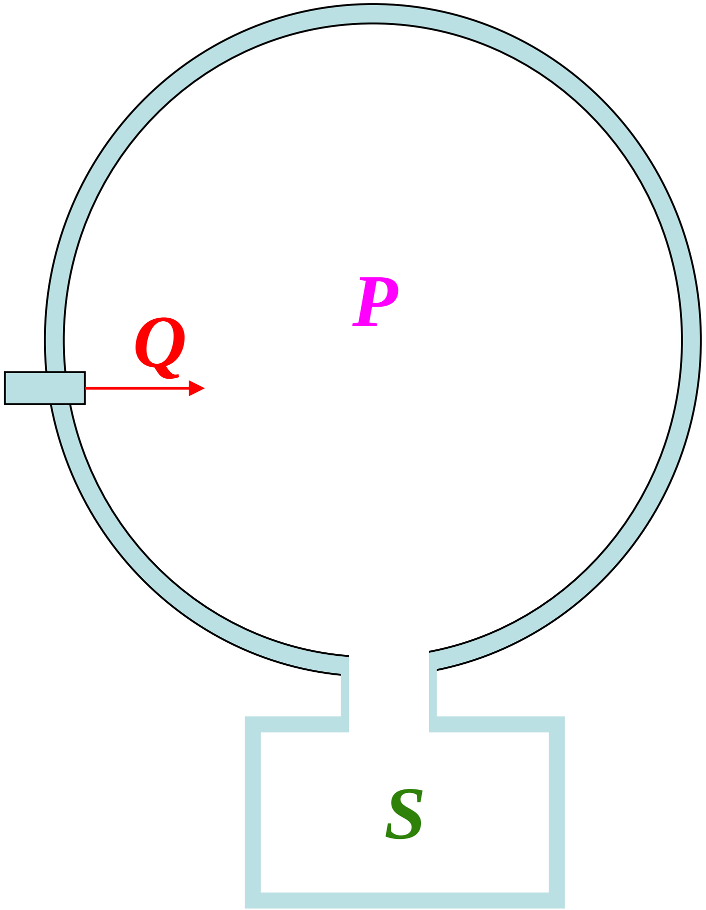
$$Q = V\frac{dP}{dt}$$

Vacuum System Performance

- Vacuum system performance is determined by
  - System Design (volume, conductance, surface, materials)
  - Gas Load or Throughput (rate gas evolves within or enters the volume)
  - Pump Performance (pump speed, compression)
- Pressure ***P*** in a vacuum vessel is defined by the total gas load, ***Q*,** and total pumping speed, ***S***.

In the case of very simple vacuum chamber it is :

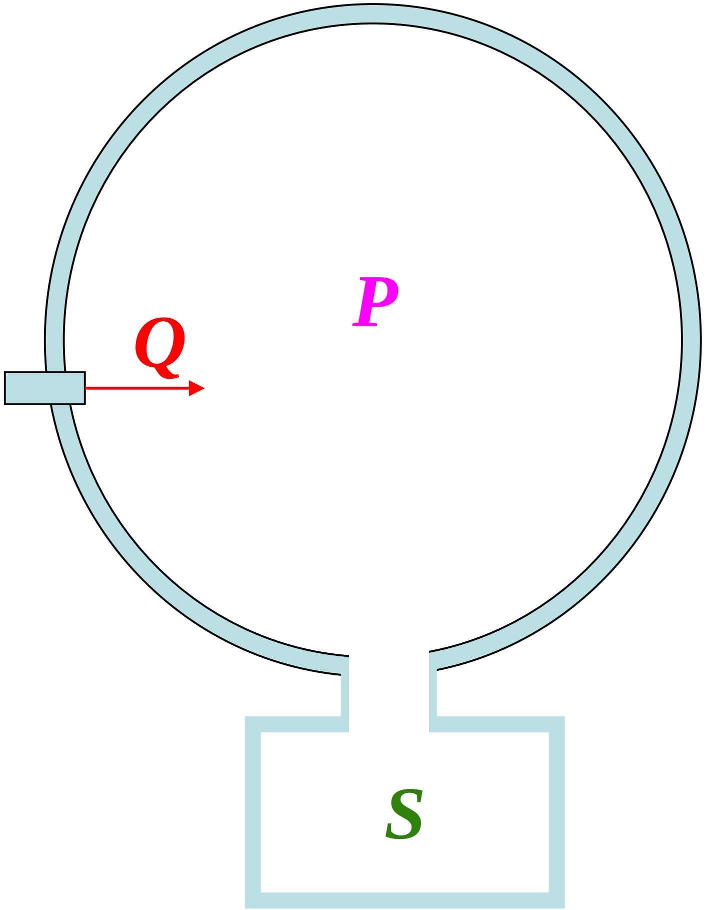
$$P = \frac{Q}{S}$$



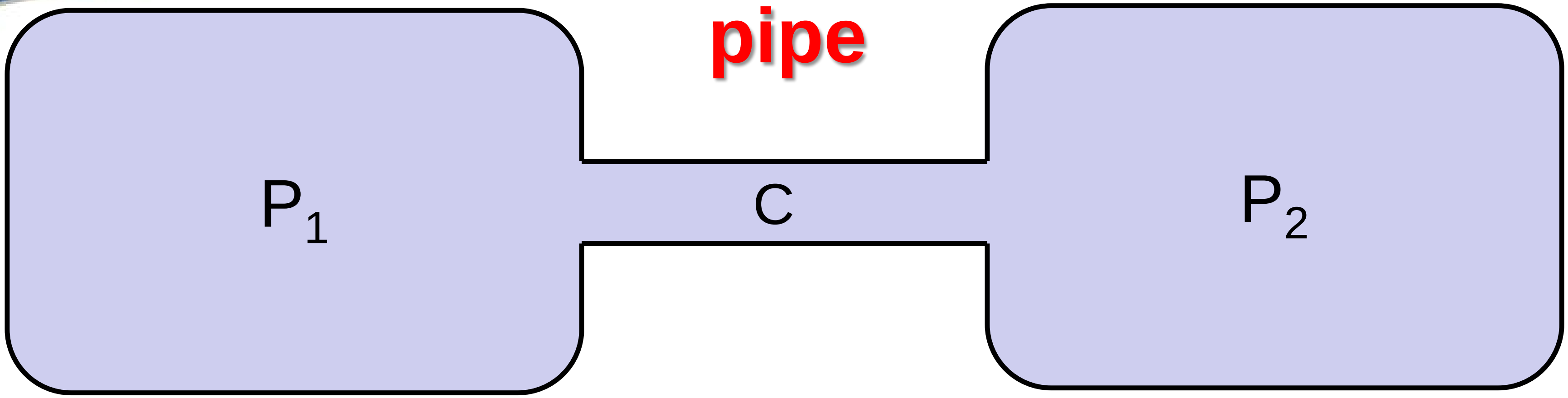
Vacuum System Performance

- What Pressure ***P*** is in a vacuum vessel with
  - the total gas load ***Q = 10⁻⁶ mbar·l/s***
  - and total pumping speed, ***S=100 l/s***?

$$P = \frac{Q}{S} =$$



Molecular flow through a cylindrical pipe



$Q = C\left(P_1 - P_2\right)$ where *C* is a vacuum conductance

For a long pipe $$C = \frac{D^3}{6L}\sqrt{\frac{2\pi RT}{M}} = 12.4\frac{D^3}{L}$$

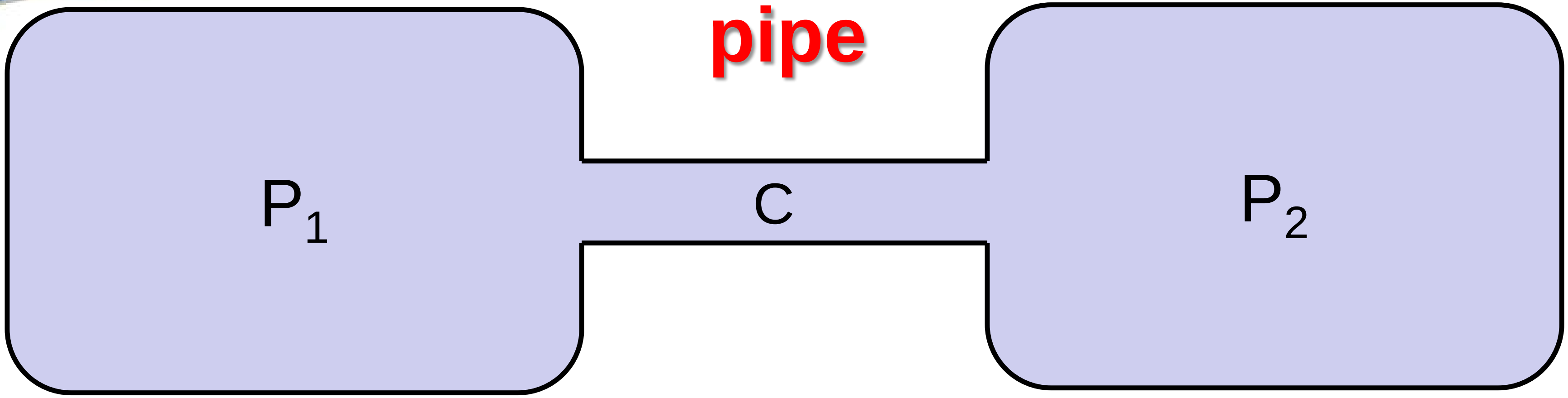
For a short pipe $$C = 12.4\frac{D^3/L}{1+4D/3L}$$

C in [l/s]

(for N_2 at 295K)

D, *L* in [cm]

Molecular flow through a cylindrical pipe



What is a gas flow *Q* between two vessels when:

- $P_1 = 2\times10^{-8}$ mbar
- $P_1 = 5\times10^{-9}$ mbar
- $C = 20$ l/s

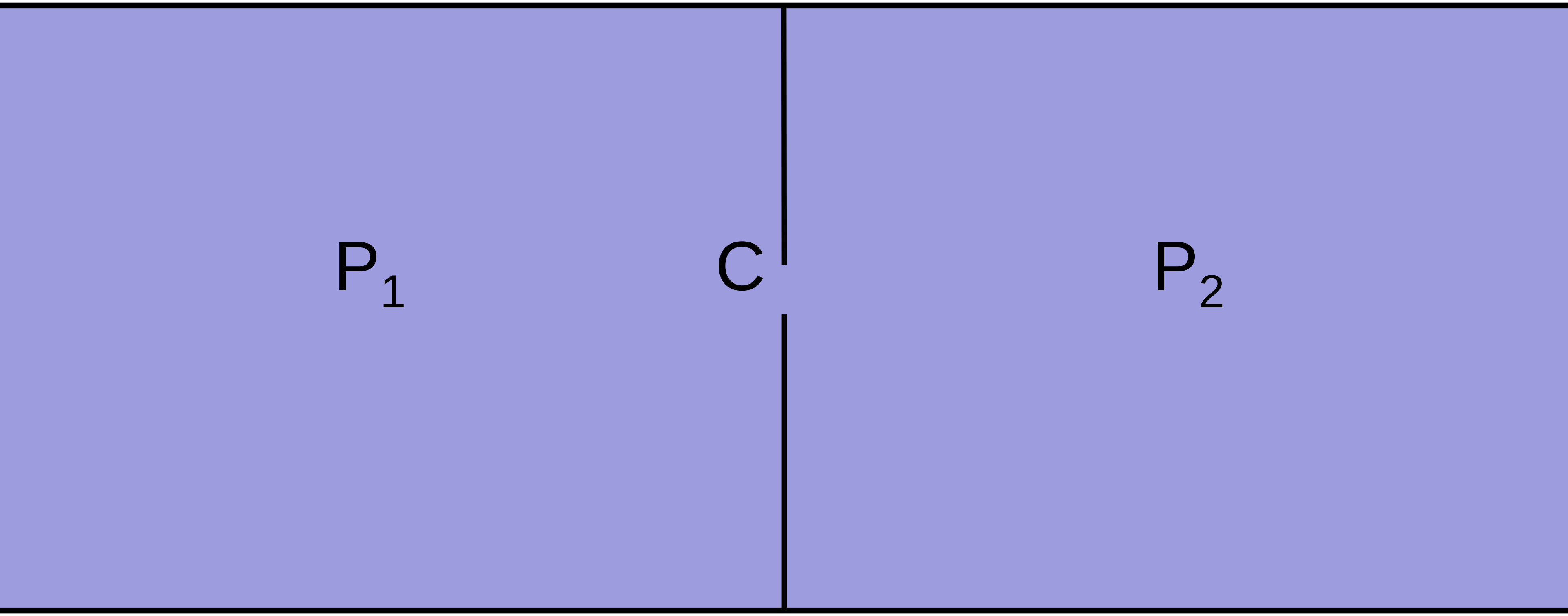
$$Q = C\left(P_1 - P_2\right) =$$

Molecular flow through a thin aperture

$$C_A = A\sqrt{\frac{RT}{2\pi M}} = 11.8A$$

[l/s] (for N_2 at 295K)

A [cm^2] – aperture area



Transmission probability

Define transmission probability, *α*, of a duct as the ratio of the flux of gas molecules at the exit aperture to the flux at the inlet aperture

i.e. $$\alpha = \frac{J_{out}}{J_{in}}$$

Then, in general, the conductance, *C*, of the duct is given by

$$C = \alpha C_A$$

Where C_A is the conductance of the entrance aperture.

Transmission probability

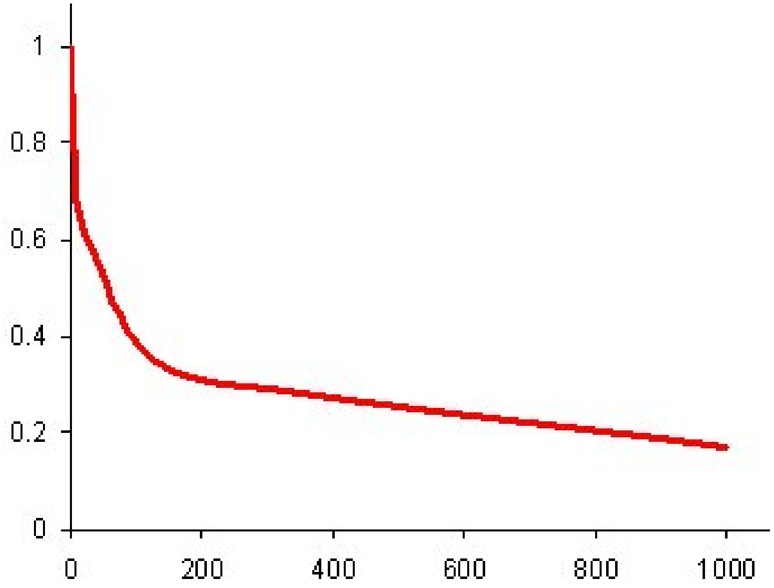
α is independent of the dimensions of the duct and depends only on the ratio of length L to transverse dimension and shape of the cross section of the duct.

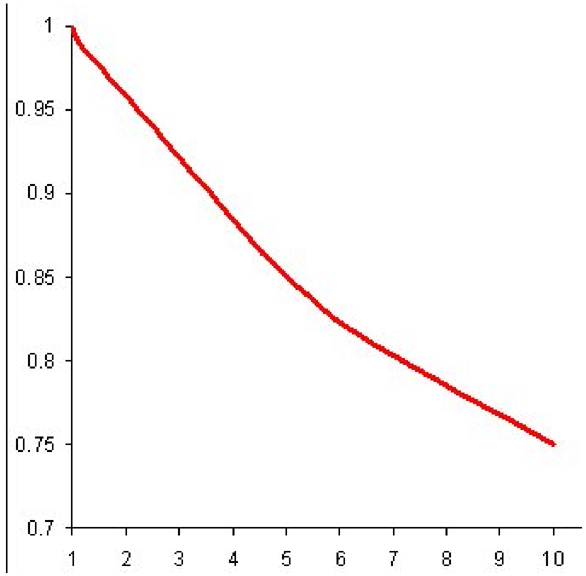
For a cylindrical pipe with a diameter d:

$^L/_D$	α
0	1
0.5	0.67
1	0.51
10	0.11
50	0.25

Non cylindrical ducts

For ducts of non circular cross section (e.g. ellipses or rectangles) an empirical correction factor can be applied to the transmission coefficient





Conductance of complex structures

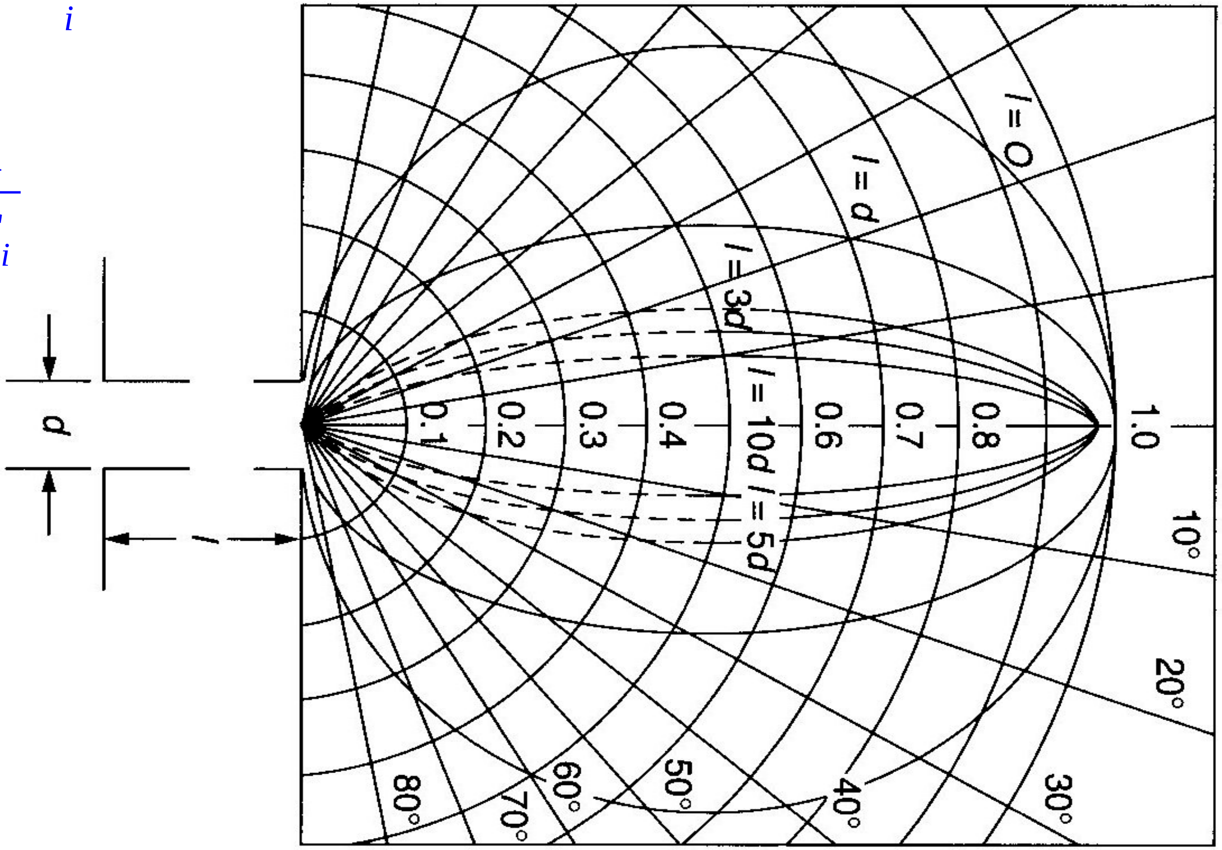
Conductances in parallel

$$C = \sum_i C_i$$

Conductances in series

$$\frac{1}{C} = \sum_i \frac{1}{C_i}$$

But this ignores beaming



Conductance of complex structures

For complex structures, e.g. bent pipes and vessel strings of varying cross section, transmission coefficients (in a molecular flow regime) are most accurately computed by methods such as

- Test Particles Monte-Carlo (TPMC) simulation
- Angular Coefficient method

Pumping in the molecular flow regime

The mechanism of pumping is that gas molecules find their way by means of a random walk into a "pump" where they are either trapped, ejected from the vacuum system or return to the vacuum system.

We can define the capture coefficient, σ, of a pump as the probability of a molecule entering the pump being retained. Then the effective pumping speed of the pump, S_e, is given by

$$S_e = \sigma C_E$$

where C_E is the conductance of the entrance aperture of the pump.

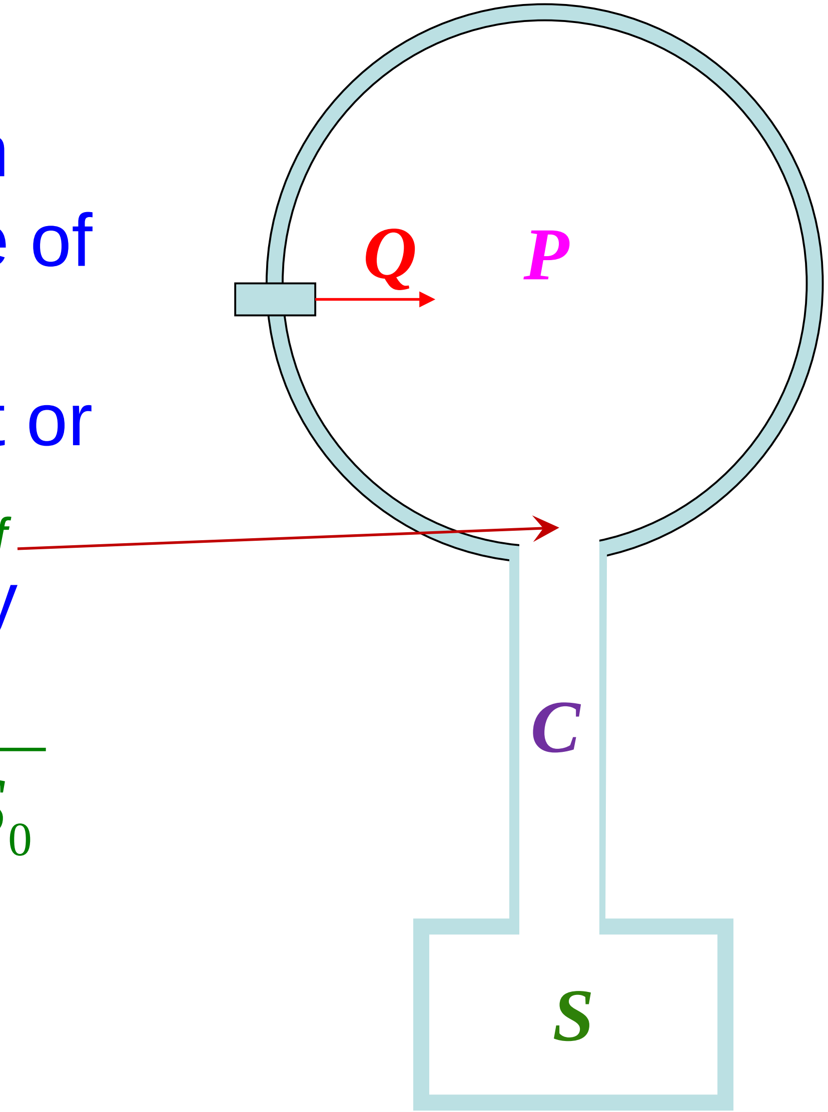
Pumping in the molecular flow regime

In general a pump will be attached to the vessel which we wish to pump with a tube of some sort. If this tube has a conductance C, then the net or effective pumping speed S_{eff} at the vessel will be given by

$$\frac{1}{S_{eff}} = \frac{1}{C} + \frac{1}{S_0} \Rightarrow S_{eff} = \frac{CS_0}{C + S_0}$$

thus

$$P = \frac{Q}{S_{eff}}$$

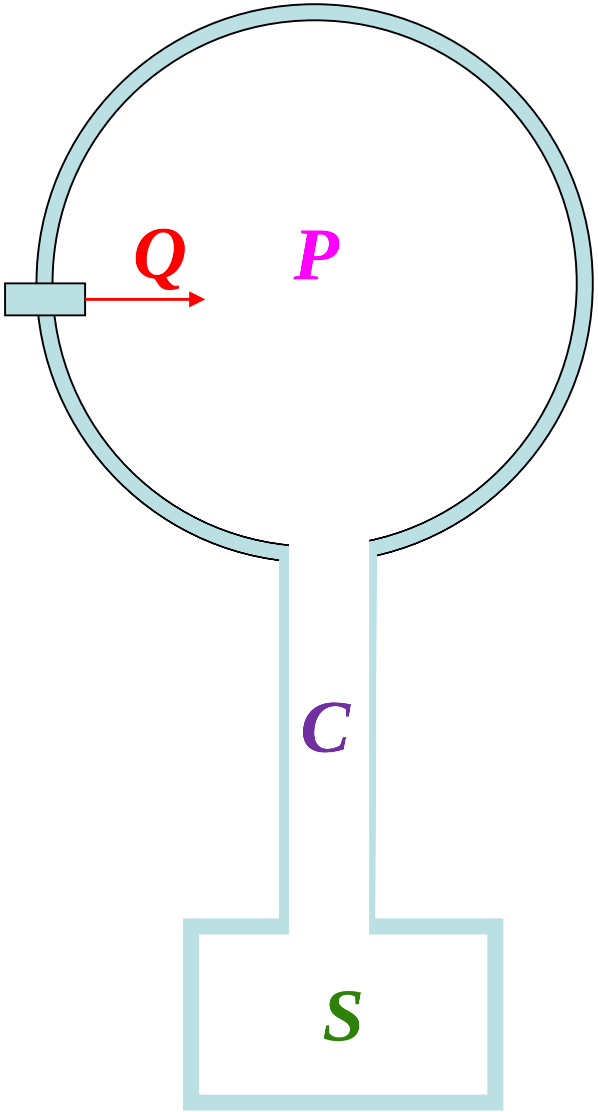


Pumping in the molecular flow regime

- Please work out what is Pressure ***P*** is in a vacuum vessel with
  - the total gas load **$Q = 10^{-6}$ mbar·l/s**
  - Conductance **$C = 10$ l/s**
  - and total pumping speed, **$S = 500$ l/s**?

$$\frac{1}{S_{eff}} = \frac{1}{C} + \frac{1}{S_0} \Rightarrow S_{eff} = \frac{CS_0}{C + S_0}$$

$$P = \frac{Q}{S_{eff}} =$$



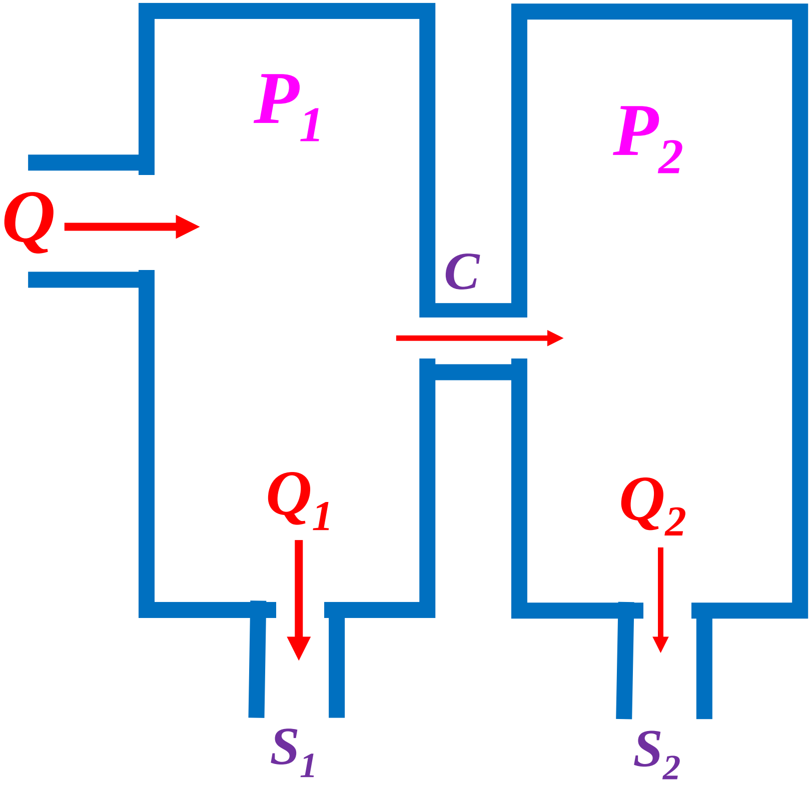
Differential Pumping

A common requirement is to maintain part of a system at a relatively low pressure while another part is at a relatively high pressure (e.g. an ion gun and a target chamber). We need to calculate the pumping speed S_2 required to maintain the pressure P_2.

Assume C is small, so

$$P_1 >> P_2$$

Please, find S_2



Vacuum Chamber at Low Temperature: P and n!

Pressure and gas density : $P = nk_BT$

Two vessels at temperatures T_1 and T_2: $T_1 > T_2$

$n_1 = n_2\sqrt{\frac{T_2}{T_1}} \Rightarrow$

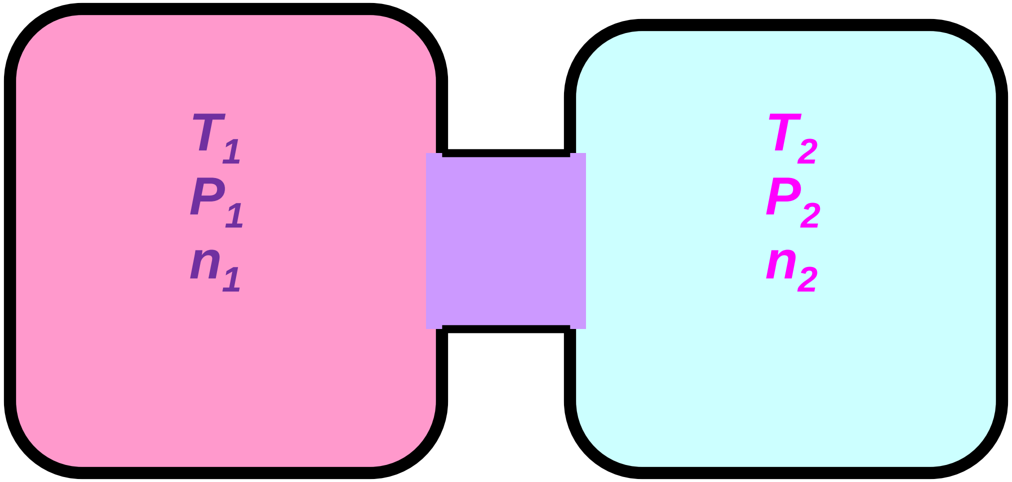
Viscous regime: $P_1 = P_2 \Rightarrow n_1 = n_2\frac{T_2}{T_1} \Rightarrow n_1 < n_2$

Molecular regime: $n_1\bar{v}_1 = n_2\bar{v}_2 \Rightarrow$

$$n_1 = n_2\sqrt{\frac{T_2}{T_1}} \Rightarrow n_1 < n_2$$

and

$$P_1 = P_2\sqrt{\frac{T_1}{T_2}} \Rightarrow P_1 > P_2$$



Questions

1) What types of beam-gas interactions may affect the beam quality of the electron machines?
2) Vacuum specifications:
   - How you will specify vacuum in the beam chamber for light source machine?
   - What is primary specification: gas density or pressure? Why?
   - How to specify for a mixture of gas?
3) If accelerator built in the Moon or on the outer space would a beam chamber be required?

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