Example The Lagoon Nebula has a 45 light-year diameter, it glows at 7500k, and has a density of 80 H $\frac{\text{atoms}}{cm^3}$

what is P? $P = \frac{N}{V} k_B T = 80\,cm^{-3}\left(\frac{100\,cm}{1\,m}\right)^3 1.38\cdot10^{-23}\frac{J}{K}(7500k)$

$= 8.3\cdot10^{-12}\,Pa$ or $8.2\cdot10^{-17}\,atm$

Concept Qs 55.html

1) $P = \frac{N}{V}kT$ or nRT don't know N or n [C]

2) [C] $N = \frac{PV}{kT}$

3) [C]

4) $K.E. = \frac{1}{2}mv_{avg}^2 = \frac{3}{2}kT$ [A]

5) $v_{avg} = \sqrt{\frac{3kT}{m}}$ Since we don't know their respective mass, we can't compare their speeds [C]

Heat capacities of gases

The K.E. of a particle is $\frac{1}{2}mv_{avg}^2 = \frac{3}{2}kT$

→ the K.E. of a gas of N particles is $N\frac{1}{2}mv_{avg}^2 = N\frac{3}{2}kT$

For a temperature change dT, $dK = N\frac{3}{2}k\,dT = n\frac{3}{2}R\,dT$

we also know that $dQ = nC_v\,dT$ where C_v is molar heat capacity at constant volume

so if $dK = dQ$ then $C_v = \frac{3}{2}R$ for an ideal gas

analogous to specific heat c for solids

Equipartition of energy

For every "degree of freedom" (of motion), a gas has energy $\frac{1}{2}kTN$

monatomic: $E = 3N\frac{1}{2}kT$, $C_v = \frac{3}{2}R$ x,y,z

diatomic: $E = (3+2)N\frac{1}{2}kT$, $C_v = \frac{5}{2}R$ x,y,z + rotation

vibrating diatomic: $E = (3+2+2)N\frac{1}{2}kT$, $C_v = \frac{7}{2}R$ x,y,z, rotation, vibration

the rotational and vibrational modes only kick in for warmer gases

hot triatomic: $E = (3+3+6)N\frac{1}{2}kT$ $C_v = \frac{12}{2}R$

Concept Q s6.html

i) C 2 translational + 1 rotational

ii) E

concept Q s9.html (see Fig 2.13 openstax)

$C_v = \frac{5}{2}R$ for a diatom at room temp

$C_v = \frac{3}{2}R$ for a monatomic gas (always)

a) $Q = nC_v\Delta T = n\frac{5}{2}R\Delta T = 1871\,J$

b) $Q = nC_v\Delta T = n\frac{3}{2}R\Delta T = 1122\,J$

Concept Q s7.html

$Q = nC_v\Delta T$ diatomic gas has higher $C_v \Rightarrow$ requires more Q for the same ΔT

A

$\Rightarrow$ energy is "wasted" on rotation

PheT simulation: States of matter

In 3 browser tabs, show Ar, Ne, O_2 at 50 K

Atomic #s Ar: $2 \cdot 18 = 36$ (actually 40 is most common isotope)

Ne: $2 \cdot 10 = 20$

O_2: $2 \cdot 2 \cdot 8 = 32$

Compare speeds; see if trend follows $v_{avg} \propto \sqrt{\frac{T}{m}}$

$v_{avg,Ar} = \sqrt{\frac{3kT}{40m_p}}$ $v_{avg,Ne} = \sqrt{\frac{3kT}{20m_p}}$ $v_{avg,O_2} = \sqrt{\frac{5kT}{32m_p}}$

$\sqrt{\frac{3}{40}} = 0.27$ $\sqrt{\frac{3}{20}} = 0.39$ $\sqrt{\frac{5}{32}} = 0.39$