Lectures: Physics 3306

Provides an introduction to a wide variety of topics in classical (pre-quantum) physics as a bridge to prepare students for subsequent upper-level courses in physics. The topics covered include thermodynamics, fluid mechanics, mechanical waves, optics, radiation, electromagnetic phenomena, atoms, and laboratory techniques. Prerequisites: C- or better in PHYS 1106; and in PHYS 1304 or PHYS 1308.

Saptaparna Bhattacharya

March 9th, 2026

Based on Simon Dalley's lectures taught in Spring 2025

Schedule

Labs

Lectures

No class

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
January	19	20	21 ✅	22	23 ✅	24	25
	26 ❄️🌨️❄❄❄	27	28 ❄️🌨️❄❄❄	29	30 ✅	31	1
February	2 ✅	3	4 ✅	5	6 ✅	7	8
	9 ✅	10	11 HWB due ✅	12	13 ✅	14	15
	16 ✅	17	18 ✅	19	20 HWC due ✅	21	22
	23 Hegi Center ✅	24	25 HWD due ✅	26	27 ✅	28	1
March	2 ✅	3	4 HWE due	5	6 ✅	7	8
	9 ✅	10	11	12	13 Midterm	14	15
	16	17	18	19	20	21	22
	23 ✅	24	25	26	27 ✅	28	29
April	30 Lecture 11	31	1 HWF due	2	3	4	5

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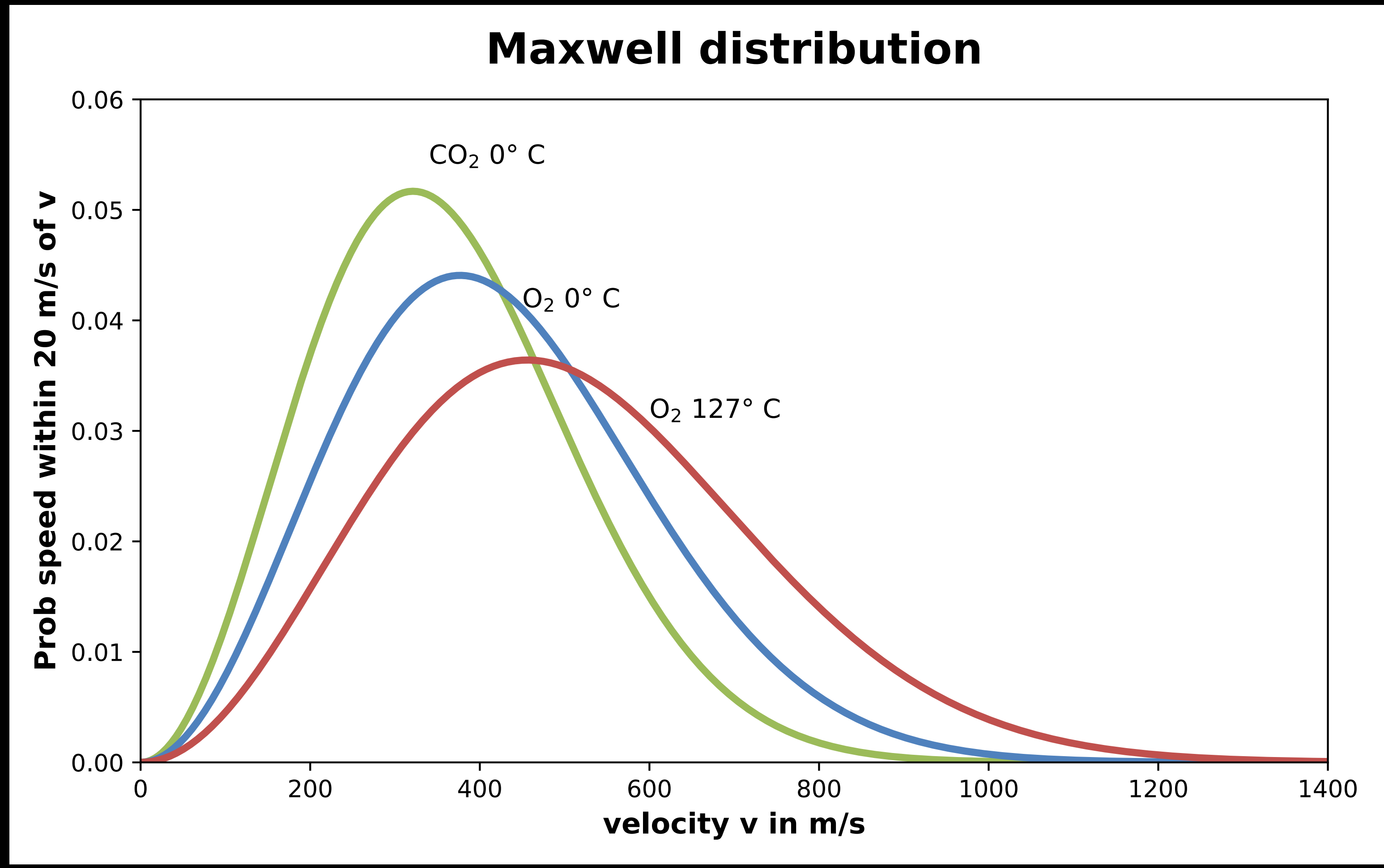
Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
April	6 Lecture 12	7	8 HWG due	9	10 Lecture 13	11	12
	13 Lecture 14	14	15 HWH due	16	17 Lecture 15	18	19
	20 Lecture 16	21	22 HWI due	23	24 Lecture 17	25	26
May	27 Lecture 18	28	29 HWJ due	30	1 Lecture 19	2	3
	4 Lecture 20	5	6	7	8	9	10

Degrees of Freedom

Halliday 19.6-19.9

Key concepts: Molecular Speeds

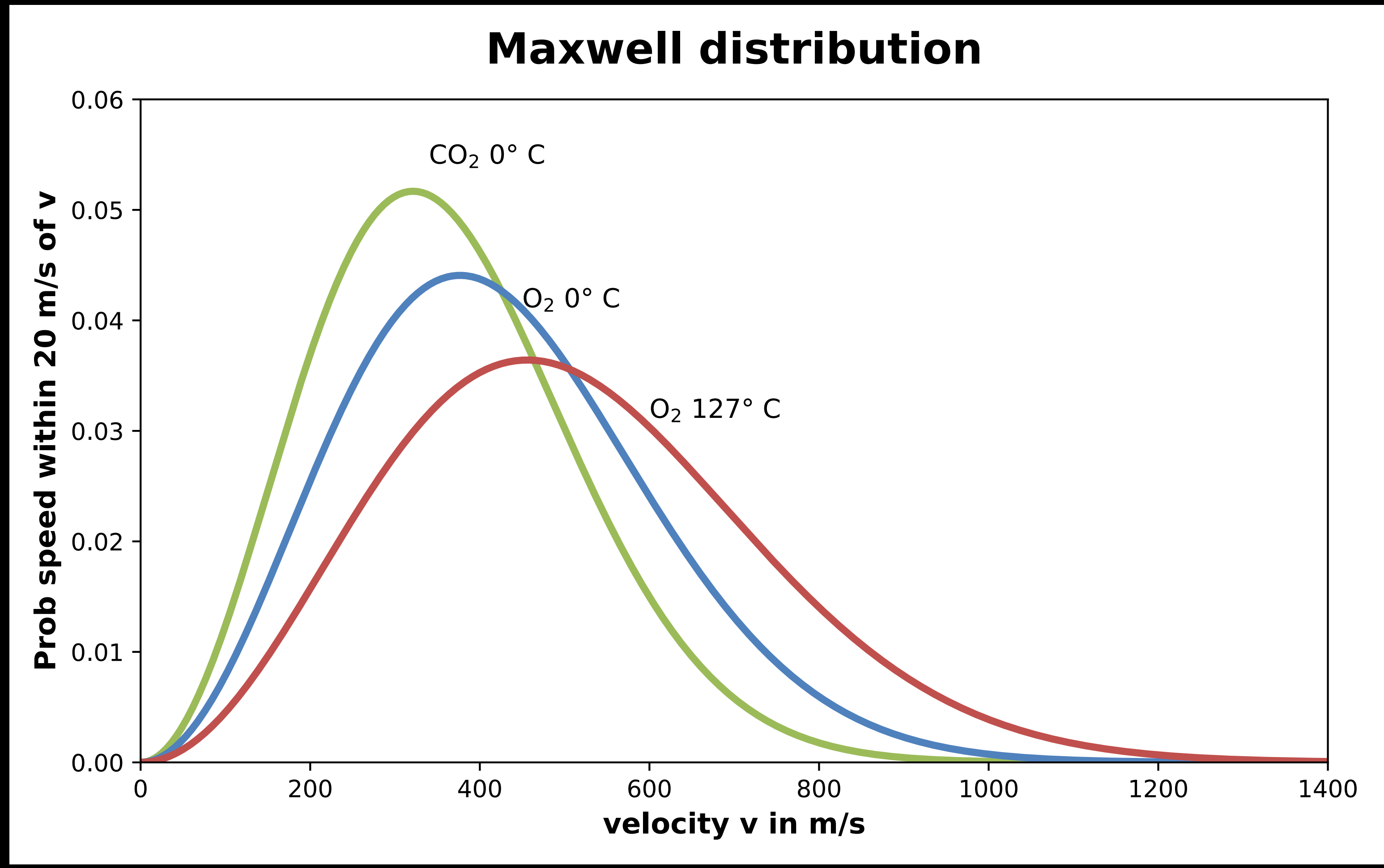
- The root-mean-squrare speed (v_{rms}) gives us a general idea of molecular speeds in a gas at a given temperature
- But we may be interested in other pertinent information:
  - What fraction of molecules have speeds twice the rms value
  - Solved by James Clerk Maxwell and known as Maxwell's speed distribution law:
  - $$P(v) = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2} v^2 e^{-Mv^2/2RT}$$
  - Fraction = area of a strip with height $P(v)$ and width dv:
  - $$\int_0^\infty P(v)dv = 1$$



- v = speed
- M = molar mass
- T = temperature
- R = gas constant

Key concepts: Molecular Speeds

- The fraction (frac) of molecules with speeds in an interval of v_1 to v_2 is then:
  - $\mathrm{frac} = \int_{\mathrm{v}_1}^{\mathrm{v}_2} \mathrm{P(v)dv}$
- Three speeds can be defined:
  - Average speed: $v_{\mathrm{avg}} = \sqrt{\frac{8RT}{\pi M}}$
  - Root-mean-square speed (average of the square of the speeds):
    - $(v^2)_{\mathrm{avg}} = \int_0^\infty v^2 P(v)dv = \frac{3RT}{M}$
    - $v_{\mathrm{rms}} = \sqrt{\frac{3RT}{M}}$



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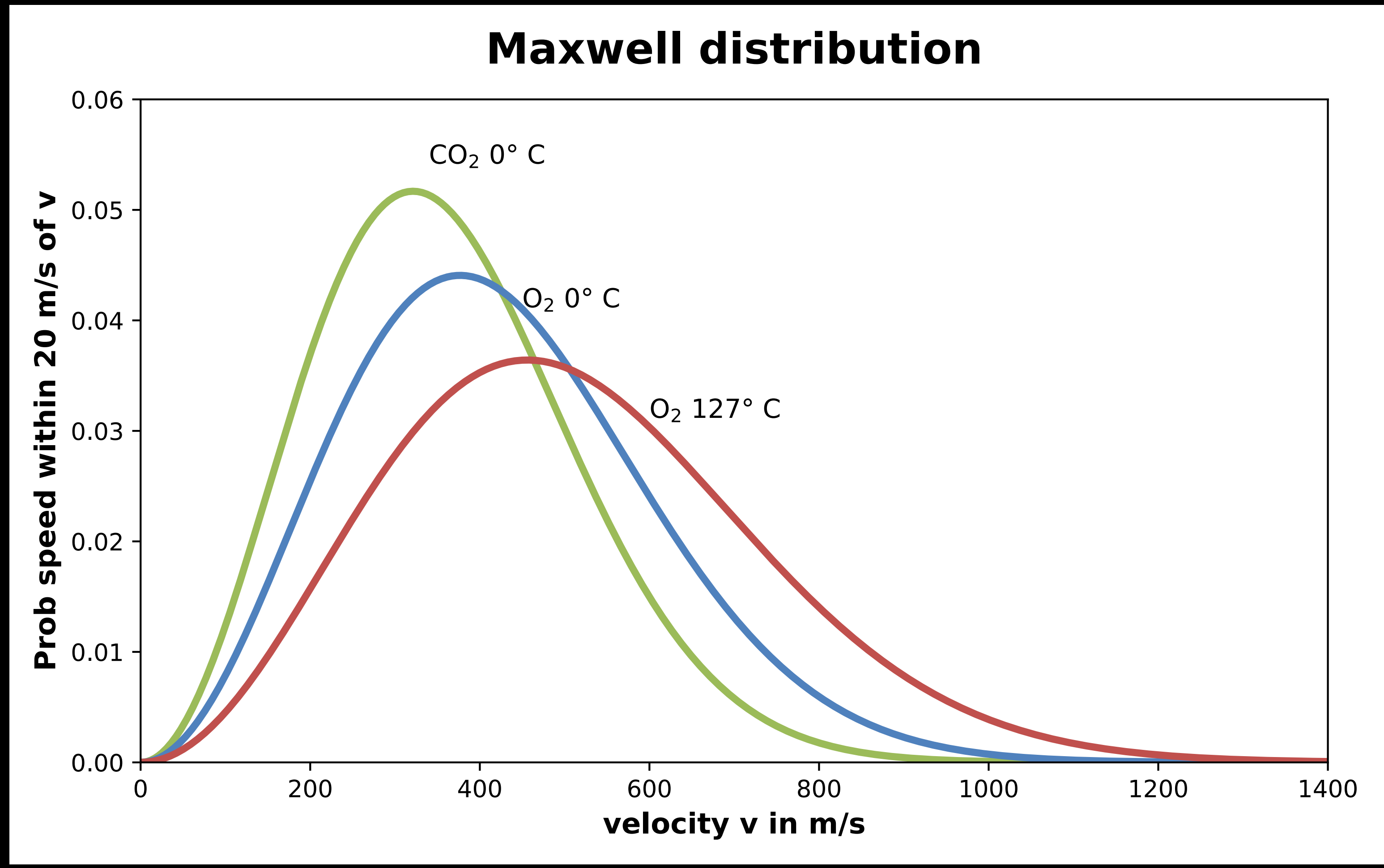
    - $v_{\text{rms}} = \sqrt{\dfrac{3RT}{M}}$
  - Most probable speed (v_p) is the speed at which $P(v)$ is maximum:
    - $\dfrac{dP}{dv} = 0, v_P = \sqrt{\dfrac{2RT}{M}}$



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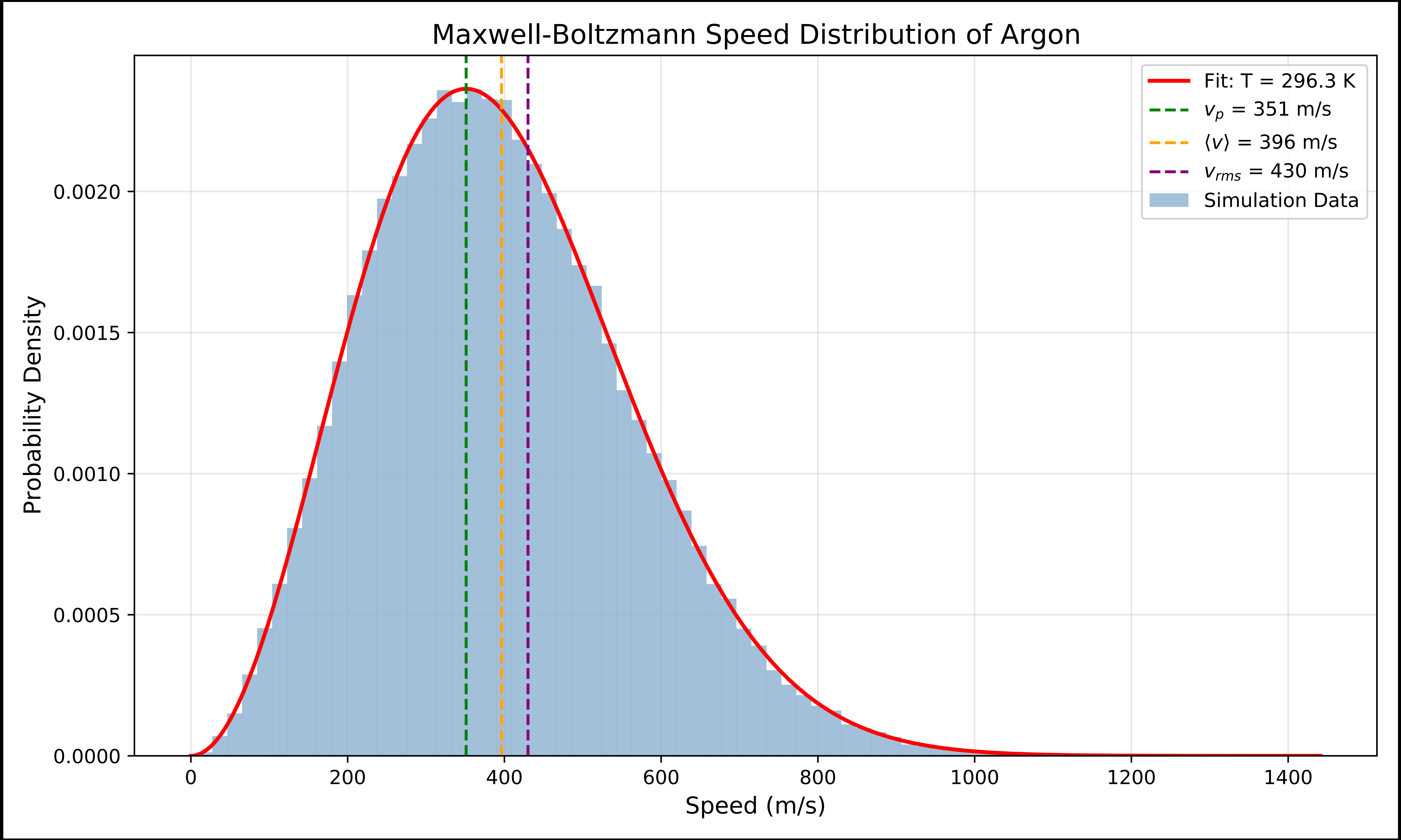
Maxwell-Boltzmann Speed Distribution of Argon
Fit: T = 296.3 K
v_p = 351 m/s
$\langle v \rangle$ = 396 m/s
v_{rms} = 430 m/s
Simulation Data
Probability Density
0.0000
0.0005
0.0010
0.0015
0.0020
0
200
400
600
800
1000
1200
1400
Speed (m/s)

For any given temperature, rank the three measures of molecular speed v_{avg}, v_p, and v_{rms}. (p = most probable)

a) $v_{rms} > v_{avg} > v_p$

b) $v_{avg} > v_p > v_{rms}$

c) $v_p > v_{avg} > v_{rms}$

d) $v_{rms} > v_p > v_{avg}$

e) $v_{avg} > v_{rms} > v_p$

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b) $v_{avg} > v_p > v_{rms}$

c) $v_p > v_{avg} > v_{rms}$

d) $v_{rms} > v_p > v_{avg}$

e) $v_{avg} > v_{rms} > v_p$

$$v_{\mathrm{rms}} = \sqrt{\frac{3RT}{M}}$$

$$v_{\mathrm{avg}} = \sqrt{\frac{8RT}{\pi M}}$$

$$v_P = \sqrt{\frac{2RT}{M}}$$

Key concepts: Internal Energy

- The average translational kinetic energy of a single atom depends only on the gas temperature
  - $K_{\text{avg}} = \frac{3}{2}kT$
  - A sample of n moles contains nN_A atoms. The internal energy (E_{int}) is the sample is then:
    - $E_{\text{int}} = (nN_A)K_{\text{avg}} = (nN_A)\left(\frac{3}{2}kT\right)$
    - $k = R/N_A, E_{\text{int}} = \frac{3}{2}nRT$

One cylinder contains helium gas and another contains krypton gas at the same temperature. Which statements are definitely true?

(I) The rms speeds of atoms in the two gases are the same.
(II) The average kinetic energies of atoms in the two gases are the same.
(III) The internal energies of 1 mole of gas in each cylinder are the same.
(IV) The pressures in the two cylinders are the same.

(a) I and II

(b) I and III

(c) II and III

(d) I and IV

(e) II and IV

One cylinder contains helium gas and another contains krypton gas at the same temperature. Which statements are definitely true?

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$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$

$$v_{\text{avg}} = \sqrt{\frac{8RT}{\pi M}}$$

$$v_P = \sqrt{\frac{2RT}{M}}$$

$k = R/N_A, E_{\text{int}} = \frac{3}{2}nRT$

The average translational kinetic energy of an ideal gas atom is directly proportional to its absolute temperature and is completely independent of its mass. It is given by the equation: $K_{\text{avg}} = \frac{3}{2}kT$

Key concepts: Molar specific heat at constant volume

- Heat Q is related to the temperature change by:
  - $Q = nC_V\Delta T$, C_V: molar specific heat at constant volume
  - $\Delta E_{int} = Q - W$
  - $\Delta E_{int} = nC_V\Delta T - W$
  - $W = 0,\ C_V = \dfrac{\Delta E_{int}}{n\Delta T}$
  - $\Delta E_{int} = \dfrac{3}{2}nR\Delta T$
  - $C_V = \dfrac{3}{2}R = 12.5\ \text{J/mol . K}$

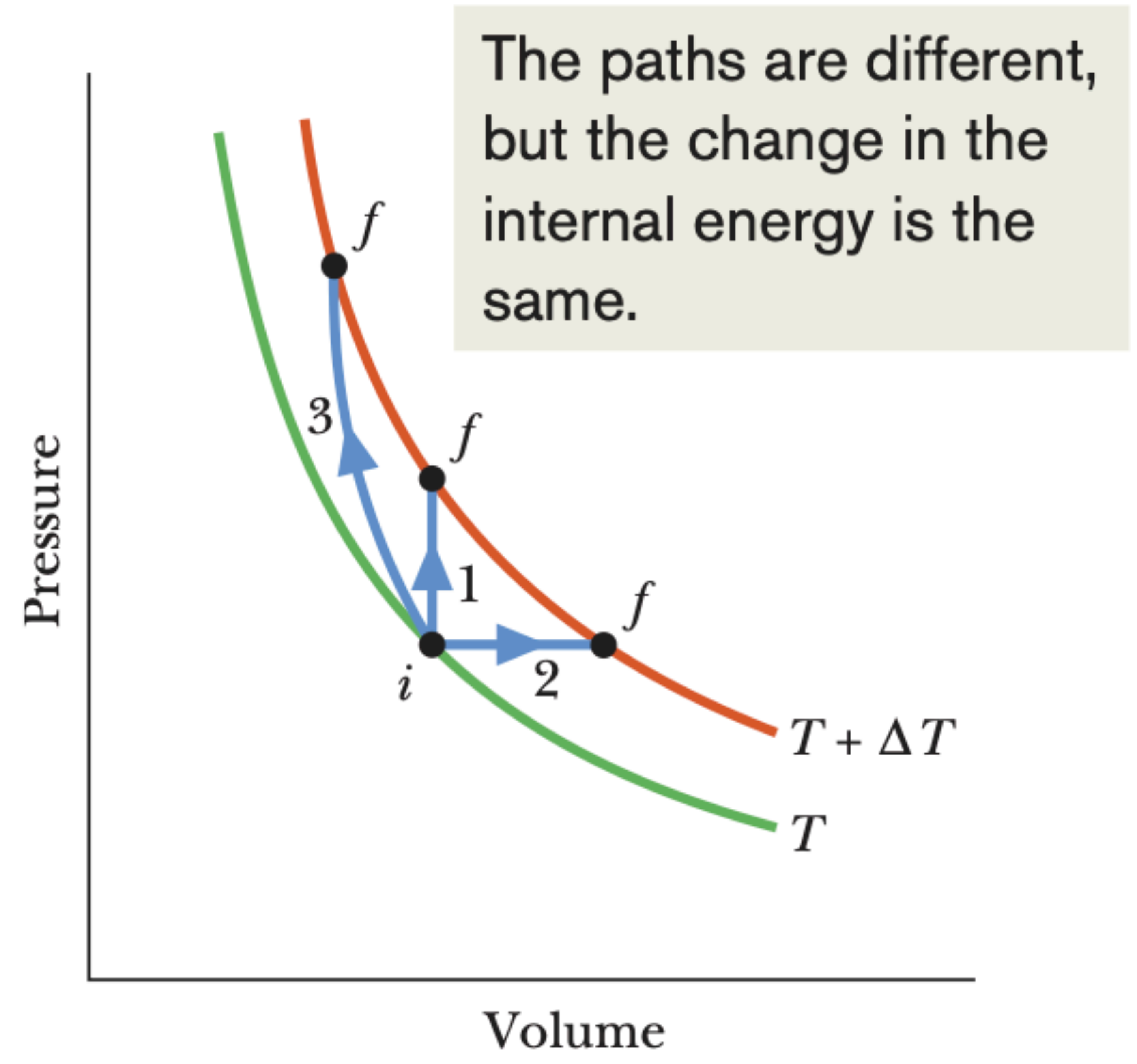

Figure 19-10 Three paths representing three different processes that take an ideal gas from an initial state i at temperature T to some final state f at temperature $T + \Delta T$. The change ΔE_{int} in the internal energy of the gas is the same for these three processes and for any others that result in the same change of temperature.

One mole of helium gas at 200 K is allowed to mix with one mole of krypton gas at 400 K in an insulated container.
What is their common temperature once mixed?

(a) Depends on their atomic masses

(b) 200 K

(c) 300 K

(d) 400 K

(e) 600 K

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The correct answer is **(c) 300 K**.

Because the container is insulated, the net heat transfer with the environment is zero. By conservation of energy, the heat gained by the helium must equal the heat lost by the krypton: $Q_{\mathrm{He}} + Q_{\mathrm{Kr}} = 0$

The heat transfer for each gas is given by $Q = nC_v\Delta T$. Both helium and krypton are noble, monatomic gases, meaning they have the same molar heat capacity at constant volume: $C_v = \frac{3}{2}R$.

Plugging in the given values ($n = 1$ mole for each gas):

$n_{\mathrm{He}}C_v(T_f - T_{\mathrm{He}}) + n_{\mathrm{Kr}}C_v(T_f - T_{\mathrm{Kr}}) = 0$

$(1)\left(\frac{3}{2}R\right)(T_f - 200) + (1)\left(\frac{3}{2}R\right)(T_f - 400) = 0$

Since $\frac{3}{2}R$ is common to both terms, we can divide it out to simplify: $(T_f - 200) + (T_f - 400) = 0$

$2T_f - 600 = 0$

$2T_f = 600$

$T_f = 300$ K

Because the molar amounts and heat capacities are identical, the final equilibrium temperature is simply the direct average of the two initial temperatures.