THERMODYNAMICS

Ideal Gas Law: Formula, Units, and Worked Examples

The single equation linking pressure, volume, temperature, and amount, its derivation from simpler gas laws, and a 10-question practice set with full solutions.

SUBJECT	LEVEL	INCLUDES
Chemistry	High school and early college	Practice set, answer key, revision sheet

Read this note online, with updates: gauravtiwari.org/study-notes/ideal-gas-law

INSIDE

The **ideal gas law** connects pressure, volume, amount of gas, and absolute temperature through $PV = nRT$. It combines Boyle's, Charles's, and Avogadro's relationships into one equation.

Most wrong answers come from unit choices, not difficult physics. Match the units of pressure and volume to the gas constant, convert Celsius to kelvin, and decide whether the problem gives moles n or particles N.

Pressure, volume, amount of gas, and absolute temperature are linked. Change one and at least one of the others must respond.

If you want to check a value before working it by hand, use the ideal gas law calculator. It keeps the unit conversion beside the result, which is where most avoidable mistakes happen.

What Is the Ideal Gas Law?

$$PV = nRT$$

Here P is absolute pressure, V volume, n amount in moles, R the molar gas constant, and T thermodynamic temperature in kelvin. The equation models particles as having negligible volume and no intermolecular forces except during elastic collisions.

QUANTITY	SYMBOL	COMMON SI UNIT
Absolute pressure	P	pascal (Pa)
Volume	V	cubic metre (m^3)
Amount of substance	n	mole (mol)
Absolute temperature	T	kelvin (K)
Molar gas constant	R	8.314462618 … $J\,mol^{-1}K^{-1}$

Because $1\ Pa\,m^3 = 1\ J$, SI units fit R directly. The OpenStax ideal-gas law guide also shows the common chemistry unit combinations.

Choosing the Right Gas Constant

The numerical value of R changes with the pressure and volume units. Do not memorize one value and force every problem to use it.

PRESSURE-VOLUME UNITS	R VALUE
Pa and m^3	$8.314462618\ Pa\,m^3 mol^{-1}K^{-1}$
kPa and L	$8.314462618\ kPa\,L\,mol^{-1}K^{-1}$
L atm	$0.082057366\ L\,atm\,mol^{-1}K^{-1}$
L bar	$0.083144626\ L\,bar\,mol^{-1}K^{-1}$

Notice that kPa·L and Pa·m^3 have the same numerical energy conversion. This makes $R = 8.314$ convenient in both of those paired unit systems.

How To Solve Ideal Gas Law Problems

The method is a unit-and-state checklist. Keep every value tied to one equilibrium state unless the equation explicitly compares two states.

1. Identify the unknown and write $PV = nRT$.
2. Convert Celsius to kelvin with $T_{\mathrm{K}} = T_{^\circ\mathrm{C}} + 273.15$.
3. Use absolute pressure, not gauge pressure, unless the question explicitly defines otherwise.
4. Choose one consistent set of units and the matching value of R.
5. Rearrange symbolically, substitute numbers, and check the physical direction of change.

Worked Example: Find the Pressure

Two moles of an ideal gas occupy $0.050\ \mathrm{m}^3$ at 300 K. Using SI units

$$P = \frac{nRT}{V} = \frac{(2.00)(8.31446)(300)}{0.050} = 9.98 \times 10^4\ \mathrm{Pa}$$

The pressure is about 99.8 kPa, close to ordinary atmospheric pressure. That scale check makes the answer plausible.

Worked Example: Find the Number of Moles

A 10.0 L cylinder contains gas at 2.00 atm and 298 K. Using $R = 0.082057\ \mathrm{L\ atm\ mol^{-1}K^{-1}}$

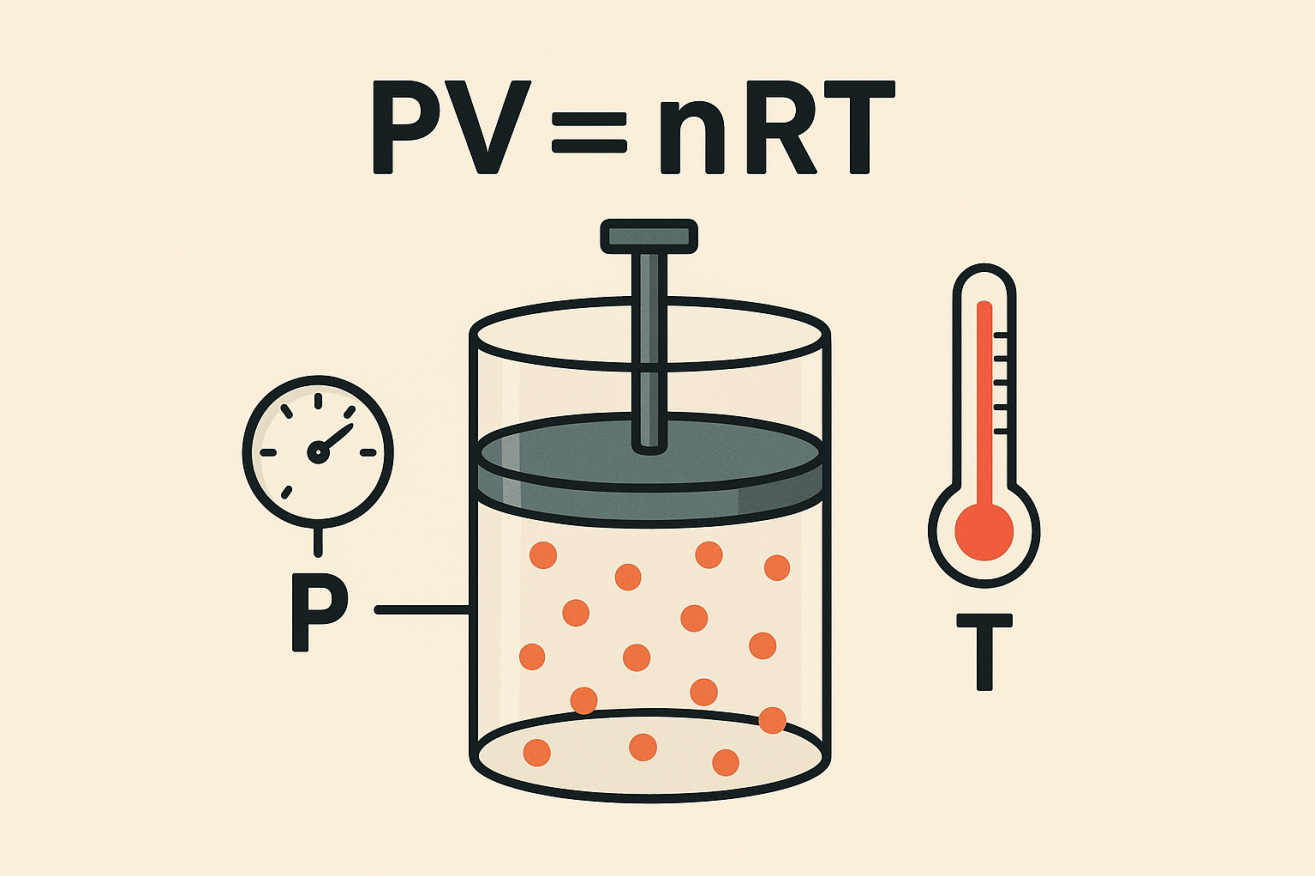
$$n = \frac{PV}{RT} = \frac{(2.00)(10.0)}{(0.082057)(298)} \approx 0.818\ \mathrm{mol}$$

The Particle Form PV = NkBT

If N is the number of molecules rather than the number of moles, the ideal-gas equation becomes

$$PV = Nk_{\mathrm{B}}T$$

Since $N = nN_A$, the two forms agree when $R = N_A k_B$. Use the Boltzmann constant when the calculation is per particle and R when it is per mole.



The ideal gas law PV = nRT - relates pressure, volume, amount of gas, and temperature for any ideal gas.

The laws of thermodynamics add energy, heat, work, and entropy to the state-variable picture. The ideal gas law is an equation of state, not a complete description of a thermodynamic process.

How the Combined Gas Laws Fit Inside

CONDITION	RESULT FROM PV = NRT	NAMED RELATIONSHIP
n and T fixed	$PV = \text{constant}$	Boyle's law
n and P fixed	$V/T = \text{constant}$	Charles's law
n and V fixed	$P/T = \text{constant}$	Amontons's law
P and T fixed	$V/n = \text{constant}$	Avogadro's law

For the same fixed sample moving between two equilibrium states, you can also write $P_1V_1/T_1 = P_2V_2/T_2$. This combined form cancels nR, but it still requires absolute temperatures and absolute pressures.

Kinetic Meaning of Pressure and Temperature

In kinetic theory, gas pressure comes from molecular momentum transferred to container walls. For a monatomic ideal gas, the mean translational kinetic energy per particle is $\frac{3}{2}k_BT$. Temperature sets the distribution's energy scale, while pressure also depends on how many particles occupy a given volume.

$$P = \frac{1}{3}\frac{N}{V}m\langle v^2\rangle$$

Combining this expression with $PV = Nk_BT$ gives $\frac{1}{2}m\langle v^2\rangle = \frac{3}{2}k_BT$. Different molecular masses therefore have different root-mean-square speeds at the same temperature.

Assumptions Behind an Ideal Gas

- Particles are much smaller than the average distance between them.
- Intermolecular potential energy is negligible except during collisions.
- Collisions between particles and walls are elastic.

- Particles move randomly and obey the statistical distribution appropriate to equilibrium.
- The gas is dilute enough that quantum statistics and molecular volume do not dominate.

Real gases approach ideal behaviour at low density and sufficiently high temperature. They deviate most near condensation, at high pressure, and when intermolecular attractions or molecular size matter.

Real Gases and the Compressibility Factor

A convenient deviation measure is the compressibility factor

$$Z = \frac{PV}{nRT}$$

An ideal gas has $Z = 1$. Values below one often indicate that attractions reduce pressure relative to the ideal prediction; values above one often indicate that excluded volume and repulsion dominate. The trend depends on temperature, pressure, and gas identity.

The OpenStax discussion of non-ideal gas behaviour explains how the van der Waals equation adds finite molecular size and attractions. It is an improvement, not a universal equation of state.

Common Mistakes

- **Using Celsius:** gas-law ratios require kelvin.
- **Using gauge pressure:** add atmospheric pressure when converting a gauge reading to absolute pressure.
- **Mismatching R:** litres and atmospheres require a different numerical value than pascals and cubic metres.
- **Confusing moles and molecules:** $PV = nRT$ uses moles; $PV = Nk_{\mathrm{B}}T$ uses particles.
- **Assuming ideal behaviour everywhere:** high pressure and low temperature can produce major deviations.
- **Mixing equilibrium states:** the equation relates state variables after the gas has a defined pressure and temperature.

Related Physics Guides

Use these next if you want to connect this result with the surrounding physics:

- Boltzmann constant and particle energy
- Macrostates and microstates
- Laws of thermodynamics

Key Takeaways

- The ideal gas law is $PV = nRT$.
- Pressure and temperature must be absolute quantities.
- The gas constant must match your pressure-volume units.
- The particle form is $PV = Nk_{\mathrm{B}}T$, with $R = N_{\mathrm{A}}k_{\mathrm{B}}$.
- Real gases are closest to ideal at low density and away from condensation.

Before touching the calculator, write the units beside every variable. That one habit catches nearly every gas-law mistake.

Practice Questions

Work each question before reading its solution. The set runs from direct recall and substitution to the applied questions that exams actually use to separate grades.

Q1. State the ideal gas law and identify each variable with its typical units.

SOLUTION

$PV = nRT$: pressure (atm or Pa), volume (L or m^3), n = moles, R = gas constant (0.0821 L·atm/mol·K, or 8.314 J/mol·K), T = ABSOLUTE temperature in kelvin, never Celsius. Using Celsius directly is the single most common error in this entire topic.

Q2. A 2.0 mol sample of gas occupies 15.0 L at 300 K. Find its pressure.

SOLUTION

$$P = \frac{nRT}{V} = \frac{2.0 \times 0.0821 \times 300}{15.0} = \frac{49.26}{15.0} \approx 3.28 \text{ atm}.$$

Q3. State Boyle's law, and show how it emerges from the ideal gas law by holding n and T constant.

SOLUTION

Boyle's law: $P_1V_1 = P_2V_2$ at constant temperature and amount. From $PV = nRT$, if n and T are fixed, nRT is a constant, so PV = constant, exactly Boyle's relationship. The historical gas laws (Boyle's, Charles's, Gay-Lussac's) are all special cases of the 1 unified ideal gas law, discovered separately before the general equation was assembled.

Q4. A gas at 2.0 atm and 4.0 L is compressed to 1.0 L at constant temperature. Find the new pressure using Boyle's law.

SOLUTION

$P_1V_1 = P_2V_2$: $2.0 \times 4.0 = P_2 \times 1.0$, so $P_2 = 8.0$ atm. Compressing to a quarter of the volume quadruples the pressure, an inverse relationship exactly as Boyle's law predicts.

Q5. A balloon holds 3.0 L of gas at 20°C. If heated to 80°C at constant pressure, find the new volume using Charles's law, remembering to convert to kelvin first.

SOLUTION

Convert: $20°C = 293$ K, $80°C = 353$ K. Charles's law: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$, so $V_2 = 3.0 \times \frac{353}{293} \approx 3.61$ L. Forgetting the kelvin conversion here would give a badly wrong answer, since Celsius has an arbitrary zero point that has no physical meaning for gas volume proportionality.

Q6. A rigid steel tank holds gas at 2.5 atm and 25°C. If left in sunlight and heated to 45°C, find the new pressure (constant volume: Gay-Lussac's law).

SOLUTION

$\frac{P_1}{T_1} = \frac{P_2}{T_2}$, with $T_1 = 298$ K, $T_2 = 318$ K: $P_2 = 2.5 \times \frac{318}{298} \approx 2.67$ atm. This is exactly why aerosol cans warn against leaving them in hot cars: rising temperature in a fixed volume drives pressure up proportionally, and past a threshold, the can ruptures.

Q7. Find the molar mass of a gas if 2.50 g occupies 1.05 L at STP (0°C, 1 atm).

SOLUTION

At STP, $n = \frac{PV}{RT} = \frac{1 \times 1.05}{0.0821 \times 273} \approx 0.0469$ mol. Molar mass $= \frac{\text{mass}}{n} = \frac{2.50}{0.0469} \approx 53.3$ g/mol. The ideal gas law is a direct route to molar mass, historically 1 of the earliest tools for identifying unknown gases before spectroscopy existed.

Q8. Find the density of nitrogen gas (N_2, M = 28 g/mol) at STP, and derive the general relationship between gas density and molar mass.

SOLUTION

Rearranging $PV = nRT$ with $n = m/M$: $PM = \frac{m}{V}RT = \rho RT$, so $\rho = \frac{PM}{RT}$. At STP: $\rho = \frac{1 \times 28}{0.0821 \times 273} \approx 1.25$ g/L. Gas density scales directly with molar mass at fixed conditions, which is exactly why helium (M=4) balloons float while carbon dioxide (M=44) sinks in air.

Q9. State 2 of the key assumptions of the ideal gas model, and explain, using 1 of them, why real gases deviate from ideal behavior at high pressure.

SOLUTION

Ideal gas particles are assumed to have (1) negligible volume compared to the container, and (2) no intermolecular attractive forces. At HIGH PRESSURE, gas molecules are forced close together, so their own finite volume becomes a non-negligible fraction of the total volume, violating assumption (1) and causing the real gas to occupy MORE volume than the ideal law predicts for the same P, n, T.

Q10. Why do real gases also deviate from ideal behavior at LOW TEMPERATURE, and what physical process does extreme deviation eventually lead to?

SOLUTION

At low temperature, molecules move slowly enough that intermolecular attractive forces (van der Waals forces), assumed negligible in the ideal model, become significant enough to noticeably pull molecules together, reducing the pressure below the ideal prediction. Taken to the extreme, this same attraction is precisely what causes gases to CONDENSE into liquids at sufficiently low temperature, a phase transition the ideal gas law, by its very assumptions, cannot describe or predict at all.

Answer Key

QUICK ANSWERS

Q1 $PV = nRT$; T must be in kelvin **Q2** ≈ 3.28 atm **Q3** $PV =$ const; follows by fixing n, T in $PV = nRT$ **Q4** 8.0 atm **Q5** ≈ 3.61 L

Q6 ≈ 2.67 atm **Q7** ≈ 53.3 g/mol **Q8** $\rho \approx 1.25$ g/L; $\rho = PM/RT$ **Q9** negligible particle volume, no intermolecular forces; high pressure breaks the negligible-volume assumption **Q10** slow molecules let intermolecular attraction matter; extreme case is condensation to liquid

Revision Sheet

The law

$PV = nRT$; T MUST be in kelvin. $R = 0.0821$ L·atm/mol·K or 8.314 J/mol·K.

Molar mass and density

$M = \frac{mRT}{PV}$; $\rho = \frac{PM}{RT}$: density scales directly with molar mass.

Component laws (fix 2 variables)

Boyle: PV=const (const T,n). Charles: V/T=const (const P,n). Gay-Lussac: P/T=const (const V,n).

Ideal assumptions

Negligible particle volume; no intermolecular forces. Both fail under real conditions.

STP

0°C (273 K), 1 atm: 1 mole of ideal gas occupies 22.4 L.

Where it breaks

High pressure (particle volume matters) and low temperature (attraction matters, leads toward condensation).

About These Notes

This note is part of a free study-notes series on gauravtiwari.org covering mathematics, physics, chemistry, and biology: the concepts that keep deciding grades in high school, board, and entrance exams.

2008	2,000+	125+	M.Sc.
Writing and teaching online since	Articles published on gauravtiwari.org	Free study notes in this series	Mathematics, with physics and chemistry training

Gaurav Tiwari is a developer, educator, and founder of Gatilab. The study-notes series exists because most exam prep material is either a full textbook or a thin definition page, and revision needs something in between: one concept, complete, with the traps named and the practice attached.

GET THE FULL SERIES

Every note in the series is free to read online and free to download as a PDF like this one. Browse the complete collection at **gauravtiwari.org/free-study-notes-exam-prep** and pick the topics your next exam actually covers.

USE IT FREELY

This PDF is free for personal study, classrooms, and study groups. Share the file or the link with anyone it can help. The one thing not allowed is reselling it or republishing it as your own work.

Gaurav Tiwari

gauravtiwari.org