

molecules make pressure, temperature is energy, and hot things glow

The gas laws and the ideal gas equation

Boyle, at constant T

$$V \propto \frac{1}{P}$$

Charles, at constant P

$$V \propto T$$

Gay-Lussac, at constant V

$$P \propto T$$

combined, for a fixed mass

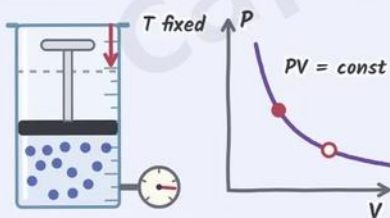
$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

ideal gas equation

$$PV = nRT$$

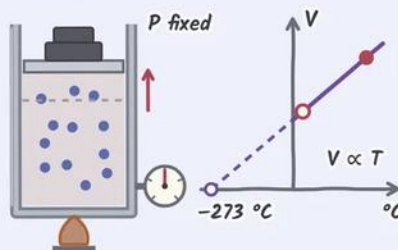
per molecule

$$PV = Nk_B T, R = N_A k_B$$

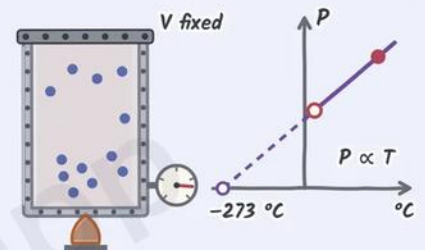


glass syringe

Boyle, T fixed, in a glass syringe: pushed in, the gauge rises; along the curve PV stays constant



Charles, P fixed by a loaded free piston in a steel cylinder: heated, the piston rises; $V \propto T$



Gay-Lussac, V fixed in a sealed, riveted steel vessel: heated, the gauge rises; $P \propto T$

T fixed: same speeds, less room, more wall hits: P rises. P fixed: harder hits lift the loaded piston until P is back. V fixed: harder and more frequent hits: P rises. Either straight line runs back to zero at absolute zero, -273.15°C . $R = 8.314 \text{ J mol}^{-1}\text{K}^{-1}$, $k_B = 1.38 \times 10^{-23} \text{ J/K}$, $n = \frac{M}{M_0} = \frac{N}{N_A}$. A relation linking P, V, T and E is an

equation of state

The assumptions behind the model

- $\sim 10^{23}$ molecules a mole: tracking one is hopeless, so the theory averages over all
- spread uniformly, moving randomly in straight lines at constant velocity between collisions
- collisions perfectly elastic, with each other and the walls: kinetic energy conserved
- force only during a collision; the collision time itself negligible
- ignoring molecule-molecule collisions for pressure is fair: the mean free path grows as P drops

Ideal gas vs real gas

Ideal

- obeys $PV = nRT$ at every pressure and temperature
- no intermolecular interactions at all
- point molecules, no volume of their own

Real

- molecules do interact, so no real gas is truly ideal
- close to ideal at low density: low pressure or high temperature
- and well above its liquefaction temperature

the gas laws hold for a real gas only while the pressure is not too high and the temperature is not near liquefaction. The ideal gas is a model for deducing real gas properties, not a substance