Thermodynamics: Visualizing Ideal Gas Processes with Python

Huzaifa Ahmed Khan[1]

[1] *Department of Physics, NED University of Engineering & Technology, Karachi, Pakistan*

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This work presents a compact, interactive simulation of ideal gas processes using Python and Jupyter notebooks. Classical thermodynamic transformations—isothermal, isobaric, isochoric, and adiabatic—are implemented with real-time sliders for state variables, allowing users to dynamically explore pressure–volume relationships and thermodynamic quantities such as work, heat, and internal energy change. By visualizing these processes on demand, the simulation bridges conceptual thermodynamics with computational intuition and provides an accessible tool for students and enthusiasts.

1 Introduction

Thermodynamics is one of the most visually intuitive yet mathematically dense areas of undergraduate physics. Despite its importance, students often struggle to connect equations with the real geometry of P–V diagrams. The goal of this project is to construct a simple but highly interactive simulation of the four fundamental ideal-gas processes:

- isothermal ($T = \text{const}$)
- isobaric ($P = \text{const}$)
- isochoric ($V = \text{const}$)
- adiabatic ($Q = 0$)

Using Python, NumPy, Matplotlib, and `ipywidgets`, each process is simulated live. As sliders are adjusted, the code recalculates pressures, temperatures, work, heat, and internal energy changes, and updates the P–V plot instantly. This transforms thermodynamics from a static chapter in a textbook into something explorable and interactive.

2 Methods

The simulation assumes an ideal monatomic gas with heat capacities $C_v = \frac{3}{2}R$ and $C_p = \frac{5}{2}R$. State variables are computed from:

$$P = \frac{nRT}{V}$$

and for the adiabatic case,

$$PV^\gamma = \text{const}, \qquad \gamma = \frac{C_p}{C_v}.$$

Work, heat, and internal energy follow standard expressions:

$$W = \int_{V_1}^{V_2} P\,dV, \qquad \Delta U = nC_v(T_2 - T_1), \qquad Q = \Delta U + W.$$

An interactive control panel lets users choose the process type and initial state, then scale one parameter (e.g., volume or temperature) by a multiplicative ratio.

3 Isothermal Process

The temperature remains constant ($T_1 = T_2$). The pressure follows the familiar hyperbola $PV = \text{const}$. Heat equals work since $\Delta U = 0$.

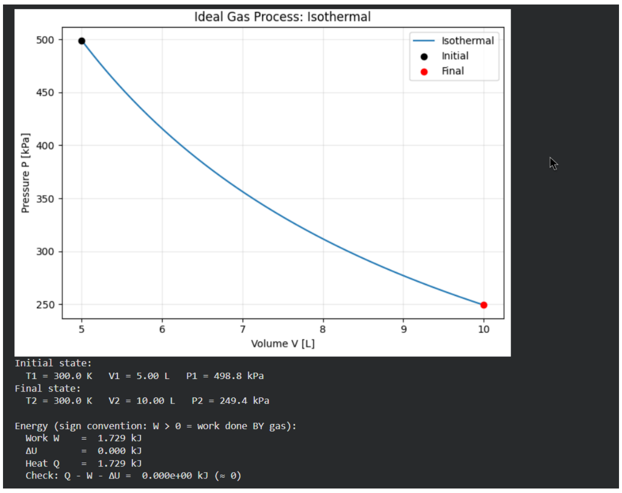

Figure 1: *Placeholder for isothermal P–V diagram.*

4 Isobaric Process

Pressure remains constant. Volume and temperature scale proportionally due to Charles' law. Work equals the rectangle area $W = P(V_2 - V_1)$.

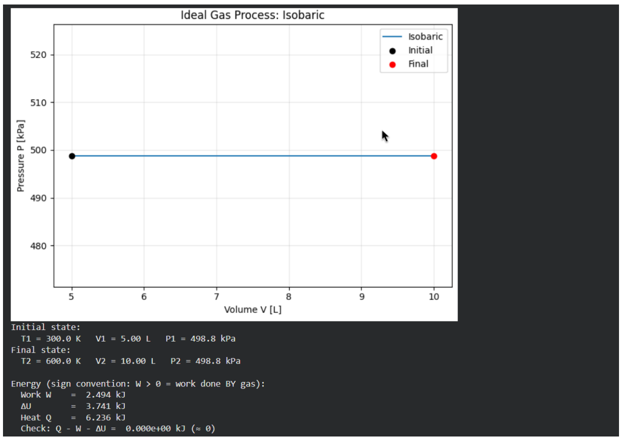

Figure 2: *Placeholder for isobaric P–V diagram.*

5 Isochoric Process

Volume stays fixed. No work is done: $W = 0$. Heat directly changes internal energy.

6 Adiabatic Process

No heat exchange ($Q = 0$). The curve is steeper than the isothermal due to the larger exponent γ.

7 Discussion

The interactive model allows students to explore thermodynamics with immediate visual feedback. Changing a single slider reveals how tightly pressure, temperature, and volume are interlinked, while energy bookkeeping reinforces the first law.

The simulation is intentionally lightweight and can be extended with:

- real gases (van der Waals, virial expansion)
- cyclic processes (Carnot, Otto, Diesel)
- entropy calculations
- animated transitions between states

8 Conclusion

This interactive thermodynamic simulator provides a clear visualization of ideal gas processes and strengthens conceptual understanding by linking equations with instantaneous diagrams. Its simplicity and extensibility make it suitable both for self-study and classroom demonstrations.

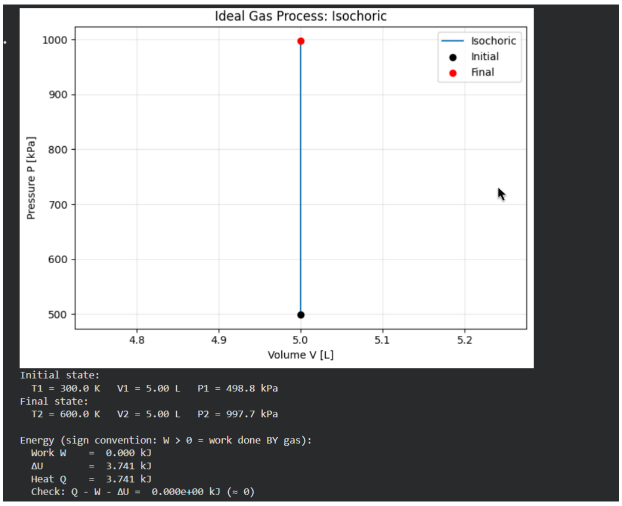

Figure 3: *Placeholder for isochoric P–V diagram.*

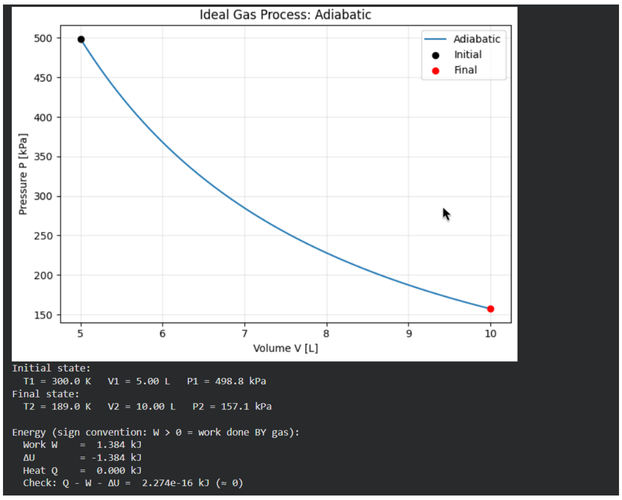

Figure 4: *Placeholder for adiabatic P–V diagram.*