

4.1 Thermodynamics and statistical mechanics

Name: _____ Class: _____ Date: _____

Total: 11 marks

KEY WORDS entropy • partition function

Objective

Apply the first and second laws with a sign convention; Relate ensembles, Boltzmann factors and entropy ; Analyse ideal gases, heat engines and quantum statistics. Original public practice; not an ETS paper.

1 Key knowledge and worked examples

State the first-law sign convention: $\Delta U = Q - W$ when W is work done by the system.

For a reversible engine between reservoirs, efficiency is bounded by $1 - T_c/T_h$ using absolute temperatures.

Boltzmann weights are $\exp(-E/kT)$. Probabilities require division by the partition function .

Distinguish Maxwell–Boltzmann, Bose–Einstein and Fermi–Dirac assumptions. Fermions cannot share an identical single-particle state.

■ Worked method

Use work W done by the gas as positive. The first law is

$$\Delta U = Q - W.$$

For reversible isothermal expansion of an ideal gas, U depends only on T , so

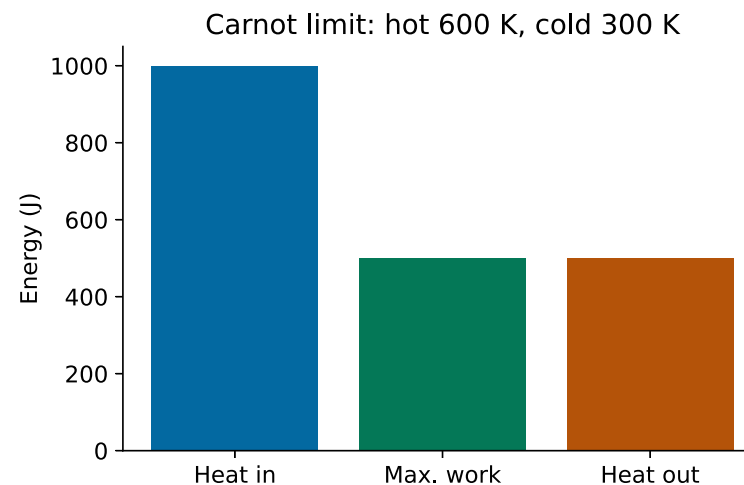
$$W = \int_{V_i}^{V_f} p dV = nRT \ln(V_f/V_i), \quad Q = W.$$

For $n = 0.50$ mol, $T = 300$ K and doubled volume,

$$W = nRT \ln 2 = (0.50 \text{ mol})(8.314 \text{ J/(mol K)})(300 \text{ K}) \ln 2 = 864 \text{ J}.$$

$$\Delta S = Q_{rev}/T = (864 \text{ J})/(300 \text{ K}) = 2.88 \text{ J/K}.$$

The gas expands and receives heat. The reservoir loses the same entropy in this reversible limit.



2 Practice

2.1 Choose one answer. A Carnot engine between 400 K and 300 K has efficiency: [1]

- A 0.25
- B 0.75
- C 1.33

2.2 Choose one answer. A higher-energy state's Boltzmann weight at fixed T is: [1]

- A greater
- B smaller
- C always identical

2.3 A system receives 100 J heat and does 40 J work. $\Delta U =$ _____ J. Show your relation and units. [2]

[2]

[5]