

## B.4 Thermodynamics

Practice Worksheet — name: \_\_\_\_\_ date: \_\_\_\_\_

### FORMULAS FOR THIS TOPIC

FIRST LAW OF THERMODYNAMICS  $Q = \Delta U + W$       WORK DONE BY A GAS  $W = P\Delta V$

INTERNAL ENERGY CHANGE  $\Delta U = \frac{3}{2}nR\Delta T$       ENTROPY CHANGE  $\Delta S = \frac{\Delta Q}{T}$       ENTROPY (STATISTICAL)  $S = k_B \ln \Omega$

ADIABATIC (MONATOMIC)  $PV^{\frac{5}{3}} = \text{constant}$       ENGINE EFFICIENCY  $\eta = \frac{\text{useful work}}{\text{input energy}}$

CARNOT EFFICIENCY  $\eta_{\max} = 1 - \frac{T_c}{T_h}$

### SECTION A — MULTIPLE CHOICE

**A1.** An ideal gas expands isothermally, absorbing 400 J of heat. The work done by the gas is:

- A 0 J
- B 267 J
- C 400 J
- D 600 J

**A2.** During an adiabatic compression of an ideal gas, its temperature:

- A Rises, because work is done on the gas and no heat escapes
- B Falls, because the gas does work
- C Stays constant, because no heat is exchanged
- D Falls, because the pressure increases

**A3.** A heat engine operates between 500 K and 300 K. Its maximum possible efficiency is:

- A 30%
- B 40%
- C 60%
- D 100%

### SECTION B — SHORT ANSWER

**B1.** An ideal monatomic gas (0.30 mol) is heated at constant pressure from 300 K to 400 K. Calculate the change in internal energy, the work done by the gas, and the heat supplied. [4 marks]

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**B2.** Using the concept of microstates, explain why a gas released into a vacuum never spontaneously returns to its original half of the container. [3 marks]

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**B3.** A refrigerator transfers heat from cold food to a warm kitchen. Explain why this does not violate the second law of thermodynamics. [2 marks]

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## ANSWER KEY

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### Section A

**A1:** 400 J — Isothermal means constant temperature, so  $\Delta U = 0$  for an ideal gas. The first law gives  $Q = 0 + W$ : all 400 J of heat becomes work done by the expanding gas.

**A2:** Rises, because work is done on the gas and no heat escapes — Adiabatic:  $Q = 0$ , so  $\Delta U = -W$ . Compression means work is done ON the gas ( $W < 0$  by our convention), so  $\Delta U > 0$  and temperature rises — the principle behind a diesel engine's ignition.

**A3:** 40% —  $\eta_{max} = 1 - T_c/T_h = 1 - 300/500 = 0.40$ . No engine between these reservoirs can beat 40%, however clever its design — that is the content of the second law.

### Section B

**B1:**  $\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}(0.30)(8.31)(100) \approx 374$  J. Work:  $W = P\Delta V = nR\Delta T = 249$  J. First law:  $Q = \Delta U + W \approx 623$  J. Note the supplied heat splits into internal energy and expansion work.

**B2:** The number of microstates  $\Omega$  for molecules spread through the whole volume is astronomically larger than for all molecules in one half. Since  $S = k_B \ln \Omega$ , the spread state has vastly higher entropy. A spontaneous return would decrease entropy of an isolated system — not forbidden by dynamics, but so improbable ( $\sim 2^{-N}$  with  $N \sim 10^{23}$ ) that it never occurs.

**B3:** The refrigerator is not isolated: electrical work is done on it. The entropy decrease of the food is more than compensated by the entropy increase of the kitchen, which receives both the extracted heat and the dissipated work — total entropy still rises.