Trent University: PHYS 2700H – Thermal Physics 2024 – 2025

Final Exam: Tuesday Apr 8, 2025 **Name:**__________________

Allowed: Formula sheet (given), calculator, 2 ½ hours

PART 1 – answer questions **1-7** in the exam booklet provided and **then** use your scratch card:
One scratch = **100%**; two scratches **33%**; three scratches **25%** (part 1 total is 40%)
PART 2 – answer questions **8–10** in the exam booklet provided (each question here is worth 20%)

Qu's 1-7) A gas of *n* moles of helium, initially at P_i, V_i and T_i, is reversibly compressed until its volume is one-third of its original volume. Treat this gas as an ideal gas.

1) If the compression takes place *isothermally*, which of the following are the correct values of the final pressure, and the change in internal energy, ΔU?

A. $P_f = 3P_i$ $\quad \Delta U = nRT_i / 2$

B. $P_f = 6.24P_i$ $\quad \Delta U = 0$

C. $P_f = 3P_i$ $\quad \Delta U = nRT_i$

D. $P_f = 3P_i$ $\quad \Delta U = 0$

E. $P_f = 2.74P_i$ $\quad \Delta U = 0$

2) If instead the compression takes place *isobarically*, which of the following are the correct values of the final temperature, and the change in internal energy, ΔU?

A. $T_f = T_i / 3$ $\quad \Delta U = -nRT_i / 2$

B. $T_f = 2.08T_i$ $\quad \Delta U = 0$

C. $T_f = T_i / 3$ $\quad \Delta U = -nRT_i$

D. $T_f = 1.10T_i$ $\quad \Delta U = 0$

E. $T_f = 3T_i$ $\quad \Delta U = nRT_i$

3) If instead the compression takes place *adiabatically*, which of the following are the correct values of the final temperature, final pressure, and the change in internal energy, ΔU?

A. $T_f = 0.48T_i$ $\quad P_f = 2.74P_i$ $\quad \Delta U = -0.62nRT_i$

B. $T_f = 2.08T_i$ $\quad P_f = 6.24P_i$ $\quad \Delta U = 1.62nRT_i$

C. $T_f = 1.46T_i$ $\quad P_f = 0.24P_i$ $\quad \Delta U = 0.69nRT_i$

D. $T_f = 0.45T_i$ $\quad P_f = 1.83P_i$ $\quad \Delta U = -0.88nRT_i$

E. $T_f = 3T_i$ $\quad P_f = 6.24P_i$ $\quad \Delta U = 3nRT_i$

4) For the *isothermal* compression of Question 1, which of the following are the correct values of *W*, the work done **on** the gas, and *Q*, the heat flow **into** the gas?

A. $W = 1.10nRT_i$ $\quad Q = -1.10nRT_i$

B. $W = 1.76nRT_i$ $\quad Q = -1.10nRT_i$

C. $W = 0.62nRT_i$ $\quad Q = -0.62nRT_i$

D. $W = 1.10nRT_i$ $\quad Q = 1.10nRT_i$

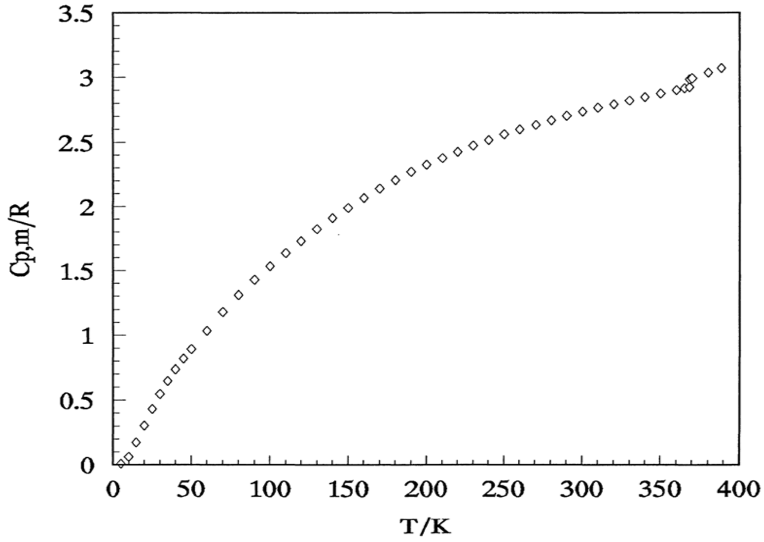
E. $W = 1.76nRT_i$ $\quad Q = -1.76nRT_i$

Qu’s 5–6:

5) Which of the following sentences best describes the second part of Eq. (5.2) on the formula sheet?

A. for any system a small change in entropy, which is a state function, is given by the small amount of heat which reversibly flows into the system, divided by the temperature T of the system at that moment, in $^\circ\mathrm{C}$.
B. for any system a small change in entropy, which is a state function, is given by the small amount of heat which reversibly flows into the system, divided by the temperature T of the system at that moment, in Kelvin.
C. for any system a small change in entropy, which is a state function like Q, is given by the small amount of heat which reversibly flows into the system, divided by the temperature T of the system at that moment, in Kelvin.
D. for any system a small change in entropy, which is a state function like Q, is given by the small amount of heat which reversibly flows out from the system, divided by the temperature T of the system at that moment, in Kelvin.
E. for any system a small change in entropy, which is a state function, is given by the small amount of heat which reversibly flows out from the system, divided by the temperature T of the system at that moment, in Kelvin.

6) Note the graph below showing the molar heat capacity of sulfur at atmospheric pressure in units of R up to $T \approx 400\ \mathrm{K}$. By using a straight edge such as your student card to split the graph into 50 K intervals, numerically estimate which of the following is the best value for the molar entropy of sulfur at 300 K compared to that at $T = 0\ \mathrm{K}$ (in fact S at 0 K is 0 J/K).



[from: B. S. Hemingway, United States Geological Survey, Open-File Report 99-324, https://doi.org/10.3133/ofr99324]

A. $S \approx 3.8R$ **B.** $S \approx 12R$ **C.** $S \approx 44R$ **D.** $S \approx 6.0R$ **E.** $S \approx 1.8R$

7) At room temperature water has a volume thermal expansion coefficient of $21\times10^{-5}\ \mathrm{K}^{-1}$ and an isothermal bulk modulus of $2.2\times10^{9}\ \mathrm{N/m^2}$. What is the approximate value of $c_P - c_v$, i.e. the difference in these specific heats, given per kg?

A. +30 kJ/kg/°C **B.** –30 J/kg/°C **C.** –300 J/kg/°C **D.** –30 kJ/kg/°C **E.** +30 J/kg/°C

PART II – answer all <u>three</u> questions in exam booklet provided

8. (a) An *ideal gas* operates as the working substance in a *Carnot engine*. Select such a process and draw this on the following diagrams, clearly labelling each diagram with the labels abcd:
i) a *PV* diagram
ii) a *PT* diagram
iii) a *UV* diagram
iv) a *UT* diagram
v) a *UH* diagram
(b) A Carnot engine with an arbitrary working substance is operated between two heat reservoirs of 400 K and 300 K.
i) If the engine receives 1200 kJ from the hot reservoir per cycle, how much heat does it reject to the cold reservoir?
ii) How much work is done in one cycle, and what is the efficiency of this Carnot engine?

9. (a) Explain the physical significance of each of the *a* and the *b* variables in the equation of state for a *van der Waals gas* and why they are zero for an ideal gas.
(b) By writing the pressure of a van der Waals gas in terms of the subtraction of two terms (each being relatively simple fractions), find the algebraic expression for the work done on a van der Waals gas when it undergoes an isothermal reversible change in volume from V_i to V_f.
(c) The van der Waals parameters for argon are $a = 0.1358\text{ Pa.m}^6/\text{mol}^2$ and $b = 3.2\times10^{-5}\text{ m}^3/\text{mol}$. Using the expression from (b) find the work done on 3 kilomoles of argon when it undergoes an isothermal compression from 60 m^3 to 30 m^3 at 298 K. How does this compare with the work done on an ideal gas experiencing the same process?

10. Consider the Gibbs function, *G*, for a *closed* system.
(a) Determine from the appropriate thermodynamic identity an expression for the entropy and the volume of the system in terms of partial derivatives of *G*.
(b) Derive the corresponding Maxwell relation.
(c) How does the thermodynamic identity change if the system were instead *open*? Find an expression for the chemical potential of the system in terms of a partial derivative of *G*.
(d) If two open systems composed of the same single substance are free to exchange particles with each other, and system 1 has a chemical potential of $\mu_1 = -0.646\text{ eV}$, while system 2 has a chemical potential of $\mu_2 = -0.346\text{ eV}$, then which way, if at all, do particles flow?