Trent University: PHYS 2700H – Thermal Physics 2021 – 2022

Midterm: Monday Feb 14, 2022 **Name:___________________**

Allowed: Formula sheet (given), calculator, 1 hour 50 minutes

PART 1 – answer questions **1-8** in pencil/pen here or in your exam booklet **then** use your scratch card:
One scratch = **100%**; two scratches **66%**; three scratches **33%**; four scratches **25%** (part 1 total is 50%)
PART 2 – answer questions **9** & **10** in the exam booklet provided (each question here is worth 25%)

Qu's 1 and 2: We apply a mathematical expression from Appendix B in Rex's *Thermal Physics*.

1) Suppose there exists an algebraic relationship between the three variables r, c, s. Which of the following then holds?

A. $\left(\frac{\partial r}{\partial c}\right)_s \left(\frac{\partial c}{\partial s}\right)_r = -\left(\frac{\partial r}{\partial s}\right)_c$

B. $\left(\frac{\partial r}{\partial c}\right)_s \left(\frac{\partial c}{\partial s}\right)_r = \left(\frac{\partial s}{\partial r}\right)_c$

C. $\left(\frac{\partial r}{\partial c}\right)_s \left(\frac{\partial c}{\partial s}\right)_r = -\left(\frac{\partial s}{\partial r}\right)_c$

D. $\left(\frac{\partial r}{\partial c}\right)_s \left(\frac{\partial c}{\partial s}\right)_r = \left(\frac{\partial r}{\partial s}\right)_c$

E. $\left(\frac{\partial r}{\partial c}\right)_s \left(\frac{\partial s}{\partial r}\right)_c = -\left(\frac{\partial c}{\partial s}\right)_r$

2) If we consider the equation of state for an ideal gas (namely, $PV = nRT$) and treat variables *r* as *P*, *c* as *V*, and *s* as *T*, which of the following expressions is on the left hand side (and therefore also the right hand side) of the correct answer to Question 1?

A. T

B. P

C. $-\frac{nR}{V}$

D. nRT

E. $\frac{V}{nR}$

Qu's 3 – 6: We consider here the energetics of vaporizing water (molecular mass of 18) into steam. At a pressure of 1.0 atm water's latent heat of vaporization (also called the *enthalpy of vaporization*) is 2257.9 kJ/kg. The density of *water* at its boiling temperature of $\approx 100\ ^\circ\mathrm{C}$ is $958.65\ \mathrm{kg/m^3}$.

3) How much heat is required to turn 10 kg of water at its boiling temperature into steam at 1 atm pressure?

A. 225.79 MJ **B.** 2.2579 MJ **C.** 22.579 MJ **D.** 2257.9 kJ **E.** 22.579 kJ

4) By approximating steam to be an ideal gas, what volume is occupied by 10 kg of steam at a pressure of 1 atm at $\approx 100\ ^\circ\mathrm{C}$?

A. $0.55\ \mathrm{dm^3}$ **B.** $0.55\ \mathrm{m^3}$ **C.** $1.7\ \mathrm{m^3}$ **D.** $22.4\ \mathrm{dm^3}$ **E.** $17\ \mathrm{m^3}$

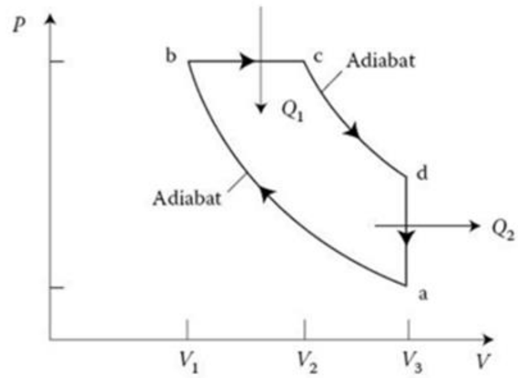
5) What work is done **by** the system against the atmosphere when 10 kg of water becomes steam?

A. +55 MJ **B.** +1.7 MJ **C.** +0.55 MJ **D.** –1.7 MJ **E.** –0.55 MJ

6) What therefore is the change in the internal energy of the 10 kg of water when it becomes steam?

A. +20.88 MJ **B.** +22.58 MJ **C.** +24.28 MJ **D.** +26.58 MJ **E.** +28.58 MJ

Qu's 7 – 8: A simplified description of a Diesel engine, with air as the working substance, is shown on the right. By treating air as an ideal gas, the theoretical efficiency of the engine can be found to be $\left(1-\frac{1}{\gamma}\left(\frac{1/r_e^{\gamma}-1/r_c^{\gamma}}{1/r_e-1/r_c}\right)\right)$, where $r_e = V_3/V_2$ (r_e is called the *expansion ratio*) and $r_c = V_3/V_1$ (r_c is called the *compression ratio*).



7) Which of the following expressions defines the *efficiency* of this engine, if *W* represents the net work done **by** the gas in one cycle?

A. $\frac{W}{Q_2}$ **B.** $\frac{W}{Q_1}$ **C.** $\frac{W}{Q_2+Q_1}$ **D.** $\frac{W}{Q_2-Q_1}$ **E.** $\frac{Q_2}{W}$

8) Suppose $r_e = 5$, and $r_c = 15$, and the working gas is an ideal *diatomic* gas. What then is the efficiency of this diesel engine?

A. 0.38 **B.** 0.44 **C.** 0.68 **D.** 0.74 **E.** 0.56

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

9. In chapter 3 we found a relationship between C_P and C_V for an ideal gas (which is listed on the formula sheet). In fact, *all* substances in a single phase obey the following equation: $C_P - C_V = T\beta^2 B_T V$.

a) By finding β and B_T for an *ideal gas*, demonstrate from this equation that the relationship from Chapter 3 for an ideal gas holds.

b) Find also β for a *van der Waal gas* in terms of the state variables *P* and *V*, and show that this reduces to that of an ideal gas when the volume of the particles is negligible ($b \to 0$) and also the interaction between them is negligible ($a \to 0$).

10. a) An *ideal gas* operates as the working substance in a *Carnot refrigerator*. Select an example of such a cycle and draw this on the following diagrams, providing for each clear labels, arrows denoting the directions of each process, and an explanation for your sketches:

i) a *PV* diagram
ii) a *PT* diagram
iii) a *UV* diagram

b) It is proposed to use a heat pump operating between the outside and the inside of a house to heat the house. The house is to be kept at $22\ °\mathrm{C}$; the outside is at $-10\ °\mathrm{C}$; and under these conditions the constant heat loss from the house is $15\ \mathrm{kW}$. What is the theoretical minimum power that such a heat pump requires?