Trent University: PHYS 2700H – Thermal Physics 2018 – 2019

Midterm: Monday Feb 11, 2019 **Name:________________**

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

PART 1 – answer questions **1-4** here or in your exam booklet, **then** use your scratch card: one scratch is **4** points; two scratches **2** points; three scratches **0.5** point (total for part 1 is worth 50%)
PART 2 – answer questions **5 & 6** in the exam booklet provided (each question is worth 25%)

Qu's 1 and 2) You wish to cool 300 g of tea in a vacuum flask which is initially at $100\,°C$.
[For these two questions the following data may be useful: specific heat of water/tea = 4.18 kJ/kg/K ; latent heat of fusion of water = 334 kJ/kg].

1) If you simply add 100 g of water at $0\ °C$, what is the final temperature at thermal equilibrium?

A. 88 °C **B.** 80 °C **C.** 77 °C **D.** 75 °C **E.** 66 °C

2) If you cool the tea instead with ice at $0\ °C$, what mass of ice is required to reach the same final temperature as in question 1?

A. 48 g **B.** 56 g **C.** 61 g **D.** 71 g **E.** 100 g

3) For an ideal gas at room temperature of $20\ °C$ and atmospheric pressure, which of the following numerical values are the correct: a) *isothermal compressibility*, and b) *volume thermal expansion coefficient*, assuming usual S.I. units, such as pressure in Pa, volume in m^3, temperature in K, etc.?

A. a) 1.013×10^{5} b) 0.04

B. a) 9.87×10^{-6} b) 0.04

C. a) 1.32×10^{-3} b) 3.41×10^{-3}

D. a) 9.87×10^{-6} b) 3.41×10^{-3}

E. a) 1.013×10^{5} b) 3.41×10^{-3}

4) The internal energy of a van der Waals gas is given by the following, where U_0 is a constant:

$$U = U_0 + C_v T - \frac{n^2 a}{V}$$

Which of the following is the correct expression for the *Joule coefficient* for this gas?

A. $-\frac{n^2 aV}{C_V T}$ **B.** $-\frac{n^2 a}{V^2 C_V}$ **C.** $-\frac{2n^2 a}{V^2 C_V}$ **D.** $-\frac{n^2 a}{2V^2 C_V}$ **E.** $-\frac{C_v TV}{n^2 a}$

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

5. a) State the two assumptions that define an *ideal gas*, and write down its equation of state.
b) Show that the equation of state for a *van der Waals gas*, which is a good representation of a real gas, can take the following form:

$$P = \frac{nRT}{V - nb} - \frac{n^2 a}{V^2} \quad .$$

c) Describe the key differences – mathematically and physically – between a van der Waals gas and an ideal gas.
d) From the equation above, find the conditions on *V* and *T* under which a van der Waals gas behaves like an ideal gas. Sketch on a *PV* diagram an arbitrary isotherm for an ideal gas and, from the equation above, determine and sketch also the corresponding isotherm for a van der Waal gas. Identify two differences in the behaviour of these isotherms.
e) For a real gas there is a particular value of *V* and *T*, called the *critical volume, V_c*, and *critical temperature, T_c*, for which the T_c isotherm has a point of inflection on the *PV* diagram (i.e. zero first derivative and zero second derivative). Show that for a van der Waals gas these quantities are:

$$V_c = 3nb \qquad \text{and} \qquad T_c = \frac{8a}{27Rb}$$

f) The van der Waals parameters for argon are: $a = 0.1358\ \text{Pa m}^6/\text{mol}^2$ and $b = 3.2\times10^{-5}\ \text{m}^3/\text{mol}$. Find for one mole of argon the corresponding values of V_c and T_c.

6. a) An *ideal gas* operates as the working substance in a *Carnot engine*. Select a single such process and draw this on the following diagrams, providing for each clear labels and an explanation:
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?