# Final Exam: Monday Apr 11, 2022 Name: _____

**Allowed: Formula sheet (given), calculator, 3 hours**

PART 1 – answer questions **1-9** 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 40%)
PART 2 – answer questions **10** – **12** in the exam booklet provided (each question here is worth 20%)

**Qu's 1 – 6:** Consider 0.51 moles of ammonia gas in a container of initial volume 10 $dm^3$ at atmospheric pressure. The van der Waals parameters for ammonia are $a = 0.4225\ m^6Pa/mol^2$ and $b = 3.707\times10^{-5}\ m^3/mol$. We shall compare the behaviour of ammonia to that of 0.51 moles of an *ideal gas* under the same initial conditions.

**1)** Which of the following statements is most correct about an ideal gas?

**A.** An ideal gas is one in which the atoms/molecules experience forces of attraction, and where the internal energy depends only on the potential energy between particles.
**B.** An ideal gas is one in which the atoms/molecules experience no forces between collisions, and where the internal energy depends only on the potential energy between particles.
**C.** An ideal gas is one in which the atoms/molecules experience forces of attraction, and where the internal energy depends only on the kinetic energy of the particles.
**D.** An ideal gas is one in which the atoms/molecules experience no forces except during collisions, and where the internal energy depends only on temperature.
**E.** An ideal gas is one in which the atoms/molecules have no volume, and where the internal energy depends only on the potential energy between particles.

**2)** Which of the following best represents the initial temperatures of both the ideal gas, and ammonia?

**A.** $T_{ideal} = 239.0$ K; $T_{ammonia} = 243.2$ K
**B.** $T_{ideal} = 241.1$ K; $T_{ammonia} = 239.0$ K
**C.** $T_{ideal} = 239.0$ K; $T_{ammonia} = 241.1$ K
**D.** $T_{ideal} = 203.1$ K; $T_{ammonia} = 205.7$ K
**E.** $T_{ideal} = 239.0$ K; $T_{ammonia} = 239.0$ K

**3)** Suppose the volume of each gas doubles to 20 $dm^3$ through a reversible process at constant pressure. Which of the following represents the work done **on** each gas during this process?

**A.** $W_{ideal} = +2027$ J; $W_{ammonia} = +2027$ J
**B.** $W_{ideal} = -1013$ J; $W_{ammonia} = -1013$ J
**C.** $W_{ideal} = +1013$ J; $W_{ammonia} = +1013$ J
**D.** $W_{ideal} = +702.3$ J; $W_{ammonia} = +704.8$ J
**E.** $W_{ideal} = -702.3$ J; $W_{ammonia} = -704.8$ J

**4)** Suppose instead that the volume of each gas expands to $20\ \text{dm}^3$ through a reversible process, while maintaining the same <u>temperature</u>. With the help of integration determine which of the following then represents the work done **on** each gas.

**A.** $W_{\text{ideal}} = -1013\ \text{J};\quad W_{\text{ammonia}} = -2027\ \text{J}$

**B.** $W_{\text{ideal}} = +702.3\ \text{J};\quad W_{\text{ammonia}} = +704.1\ \text{J}$

**C.** $W_{\text{ideal}} = -702.3\ \text{J};\quad W_{\text{ammonia}} = -704.1\ \text{J}$

**D.** $W_{\text{ideal}} = -702.3\ \text{J};\quad W_{\text{ammonia}} = -719.9\ \text{J}$

**E.** $W_{\text{ideal}} = -702.3\ \text{J};\quad W_{\text{ammonia}} = -712.3\ \text{J}$

**5)** The change in internal energy of a van der Waals gas with volume when held at constant temperature can be derived from Eqn. (8.2) on the formula sheet to be $\left(\partial U / \partial V\right)_T = n^2 a / V^2$. By applying this expression to the isothermal expansion for ammonia, which of the following best represents the change in internal energy of each gas under the isothermal expansion?

**A.** $\Delta U_{\text{ideal}} = +5.6\ \text{J};\quad \Delta U_{\text{ammonia}} = +5.8\ \text{J}$

**B.** $\Delta U_{\text{ideal}} = 0\ \text{J};\quad \Delta U_{\text{ammonia}} = +5.8\ \text{J}$

**C.** $\Delta U_{\text{ideal}} = +5.2\ \text{J};\quad \Delta U_{\text{ammonia}} = +5.6\ \text{J}$

**D.** $\Delta U_{\text{ideal}} = +5.6\ \text{J};\quad \Delta U_{\text{ammonia}} = +5.8\ \text{J}$

**E.** $\Delta U_{\text{ideal}} = 0\ \text{J};\quad \Delta U_{\text{ammonia}} = +5.5\ \text{J}$

**6)** From the above which of the following then represents the total heat flow **into** each gas during their isothermal expansion?

**A.** $Q_{\text{ideal}} = +702.3\ \text{J};\quad Q_{\text{ammonia}} = +709.6\ \text{J}$

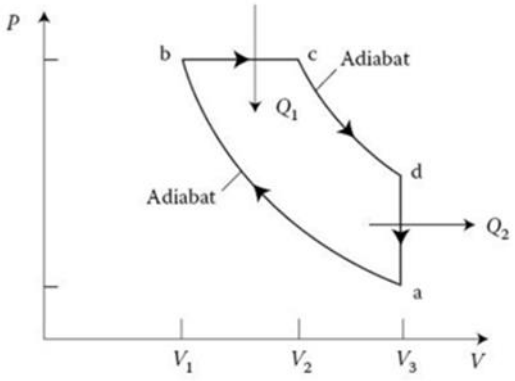
**B.** $Q_{\text{ideal}} = -709.6\ \text{J};\quad Q_{\text{ammonia}} = -702.3\ \text{J}$

**C.** $Q_{\text{ideal}} = +702.3\ \text{J};\quad Q_{\text{ammonia}} = +698.6\ \text{J}$

**D.** $Q_{\text{ideal}} = +709.6\ \text{J};\quad Q_{\text{ammonia}} = +702.3\ \text{J}$

**E.** $Q_{\text{ideal}} = +702.3\ \text{J};\quad Q_{\text{ammonia}} = +712.4\ \text{J}$

**Qu's 7 – 9:** A theoretical model for the Diesel engine, with air as the working substance, is shown on the right. By treating the air as an ideal gas, the 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 such an engine, if *W* represents the net work done **by** the gas in one cycle?

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

**8)** Suppose $r_e = 5$, and $r_c = 15$, and treat air as 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

**9)** Given these values of $r_e = 5$, and $r_c = 15$, determine from the adiabatic compression step shown the ratio of the *highest* to *lowest* pressures experienced by the air. What is this ratio?

**A.** 38:1 **B.** 44:1 **C.** 68:1 **D.** 74:1 **E.** 56:1

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

**10.** Suppose we have two identical samples of a substance with heat capacity $C_p$: a colder one at a temperature of $T_1$ and a hotter one at $T_2$. The two samples are placed in thermal contact but otherwise isolated from the environment. We assume the heat capacity to be constant with temperature.
**a)** What is the final temperature of the two samples?
**b)** What is the change in entropy of each sample?
**c)** What is the expression for the total change in entropy of the universe?

**11. a)** Derive the *thermodynamic identity* for the Helmholtz free energy (so find $dF$) for a closed system (namely, containing a fixed number of particles).
**b)** Determine from this an expression for the entropy and pressure of the system in terms of partial derivatives of *F*.
**c)** Derive the corresponding Maxwell relation from $dF$.
**d)** How does your answer to (a) change if the system were instead *open* (so can now gain or lose particles)? Determine an expression for the chemical potential of the system in terms of a partial derivative of *F*.

**12.** The *P-T* phase diagram of ammonia can be characterized by the following information. At atmospheric pressure the melting and boiling temperatures are $195.46\ \text{K}$ and $239.82\ \text{K}$, respectively. The triple point pressure and temperature are $6077\ \text{Pa}$ and $195.41\ \text{K}$, respectively. The critical point pressure and temperature are $112.8\times10^5\ \text{Pa}$ and $405.5\ \text{K}$.
**a)** By relating the values for pressure given above to atmospheric pressure, sketch the *P-T* phase diagram for ammonia (labelled carefully, but not drawn to scale).
**b)** For each of the following four points place a clearly labelled point on the phase diagram, and for each point state which and how many phases are present:
I: 195.41 K, 9506 Pa
II: 195.41 K, 6077 Pa
III: 245.45 K, 101325 Pa
IV: 185.5 K, 6077 Pa