

Final Exam: Monday Apr 18, 2023 Name: _____**Allowed: Formula sheet (given), calculator, 2½ hours**PART 1 – answer questions **1-7** in pencil/pen in your exam booklet **then** use your scratch card:One scratch = **100%**; two scratches **50%**; three scratches **33%**; four 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 1-2)** We consider here the *isothermal compressibility*, κ_T , of a gas.1) Which of the following expressions is the isothermal compressibility of an *ideal gas* in terms of its state variables?

A. nPV/R

B. $1/nP$

C. V/RT

D. $1/T$

E. V/nRT

2) Using dimensional analysis and/or understanding of what is meant by an *intensive* vs. *extensive* quantity, or otherwise, which of the following expressions may plausibly be the isothermal compressibility of a *van der Waals gas*?

A. $\frac{nR}{V-nb}$

B. $\frac{\left(1-\frac{nb}{V}\right)}{P+\frac{2n^2ab}{V^3}}$

C. $\frac{-nRT}{(V-nb)^2} + \frac{2n^2a}{V^3}$

D. $\frac{\left(1-\frac{nb}{V}\right)}{P-\frac{n^2a}{V^2}+\frac{2n^3ab}{V^3}}$

E. $\frac{\left(1-\frac{b}{V}\right)}{P-\frac{n^2a}{V^2}+\frac{2n^3ab}{V^3}}$

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

A. If in an infinitesimal, reversible, process a small amount of heat, δQ_R , flows into a substance at temperature T , where δQ_R is usually measured in Joules and T in degrees Celsius, then the small change in its entropy S , which is a state function, is given by dS .B. If in an infinitesimal, reversible, process a small amount of heat, δQ_R , flows into a substance at temperature T , where δQ_R is usually measured in Joules and T in Kelvin, then the small change in its entropy S , which is a state function, is given by dS .C. If in any infinitesimal process a small amount of heat, δQ_R , flows into a substance at temperature T , where δQ_R is usually measured in Joules and T in Kelvin, then the small change in its entropy S , which is a state function, is given by dS .D. If in an infinitesimal, reversible, process a small amount of heat, δQ_R , flows into a substance at temperature T , where δQ_R is usually measured in Joules and T in Kelvin, then the small change in its entropy S , which is a state function just like Q , is given by dS .E. If in an infinitesimal, reversible, process a small amount of heat, δQ_R , flows out from a substance at temperature T , where δQ_R is usually measured in Joules and T in Kelvin, then the small change in its entropy S , which is a state function, is given by dS .

Qu's 4–5) You decide to install a Carnot refrigerator in your kitchen, with a room temperature of 300 K. While running continuously this fridge/freezer uses 60 W of electrical power and expels 360 W of heat into the kitchen.

4) What is the coefficient of performance for the fridge/freezer?

- A.** 6 **B.** 1.2 **C.** 0.20 **D.** 1 **E.** 5

5) What is the coldest temperature that is physically possible inside this fridge/freezer?

- A.** -3°C **B.** -13°C **C.** -23°C **D.** -33°C **E.** -43°C

Qu's 6–7) We use here the following information for the vaporization of H_2O at 100°C and 1 atm: latent heat is 2257 kJ/kg ; specific volume of water is $1.043 \times 10^{-3} \text{ m}^3/\text{kg}$; specific volume of steam is $1.672 \text{ m}^3/\text{kg}$.

6) What is the slope of the *vaporization curve* $P(T)$ at 100°C and 1 atm?

- A.** +3620 Pa/K **B.** +3.62 Pa/K **C.** -3620 Pa/K **D.** -3.62 Pa/K **E.** +1350 Pa/K

7) Mount Washington in New Hampshire is the tallest mountain in the Northeastern US, and the pressure at its summit is close to 600 mm of mercury (1 atm = 760 mm Hg, as per the formula sheet). What does the result from Question 6 indicate for the boiling temperature of water at the summit of Mount Washington?

- A.** 98°C **B.** 94°C **C.** 91°C **D.** 88°C **E.** 85°C

PART II – answer all three questions in exam booklet provided

8) The equation of state for an elastic material connects the tension F , the length L , and the temperature T . For a stretched elastic band this is:

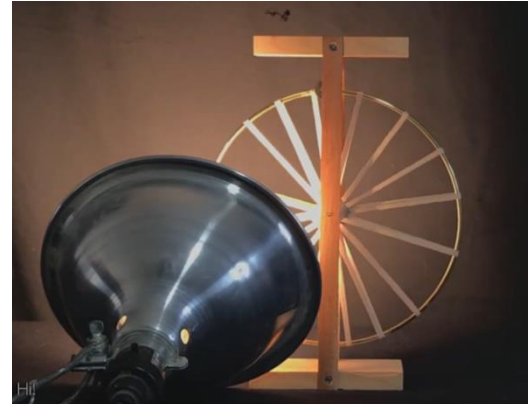
$$F = aT \left[\frac{L}{L_0} - \left(\frac{L_0}{L} \right)^2 \right],$$

where L_0 is the unstretched length, T is in Kelvin, and $a = 1.3 \times 10^{-2}$ N/K.

a) Sketch on the same graph $F(L)$ at two temperatures, T_1 and $\approx 1.1T_1$, for values of L from L_0 to $2L_0$.

b) How much work is done **by** an elastic band of unstretched length 10 cm when it isothermally and reversibly shrinks from 11.1 cm to 11.0 cm at a temperature of 49 °C?

c) Consider the rubber band heat engine video that we saw in class, with screenshot shown on the right. Make a rough but clear and labelled, $F-L$ plot showing a *possible* cycle for the elastic band (the working substance of this engine), with directions shown. Assume that the shrinking and expansion of the elastic band happens isothermally at the two temperatures of part (a).



Screenshot from *The Rubber Band Heat Engine*, Douglas Stith,
<https://www.youtube.com/watch?v=jMBhF-1K-4U>

9. Consider the Helmholtz free energy, F , for a *closed* system.

a) Determine from the appropriate thermodynamic identity an expression for the entropy and the pressure of the system in terms of partial derivatives of F .

b) Derive the corresponding Maxwell relation.

c) How does the thermodynamic identity change if the system were instead *open* (so can now gain or lose particles)? Find an expression for the chemical potential of the system in terms of a partial derivative of F .

10) Calcium carbonate can adopt one of two common crystalline forms: *calcite* and *aragonite*.

Some thermodynamic data at room temperature and pressure for these two forms of calcium carbonate is given below:

	g (kJ/mol)	s (J/K.mol)	c_p (J/K.mol)	v (cm ³ /mol)
Calcite	-1128.8	92.9	81.88	36.93
Aragonite	-1127.8	88.7	81.25	34.15

a) Which of these two forms of calcium carbonate do you expect to be more stable at room temperature and pressure?

b) Relative to the other form, does this stable form become more or less stable as the temperature increases at constant pressure (and explain why)?

c) Find the pressure at room temperature at which the other phase becomes more stable.