University of Ottawa
Department of Physics
PHY1122 - Fundamentals of Physics II
Midterm Examination - February 28, 2014
Examiner: Michael Rogers
VERSION A

This is a closed book exam.
You are allowed a one-sided sheet of notes written on 8.5×11 inch which you will pass in with your exam.
You are also allowed a calculator.
Answer all 5 questions, worth a total of 100 marks.
You have 75 minutes.

Question 1 (25 marks) Ethanol has a boiling point of 78.0°C, a freezing point of -114.0°C, a heat of vaporization of 879 kJ/kg, a heat of fusion of 109 kJ/kg, and a specific heat of 2.43 kJ/kg·K. The molar mass of ethanol is 46.07 g/mol.

(a) **(10 Marks)** How much energy must be removed from 11.07 mol of ethanol that is initially a gas at 78.0°C so that it becomes a solid at -114.0°C?

(b) **(10 Marks)** A mixture of 1510 g of liquid ethanol and 490 g of solid ethanol is in an initial equilibrium state at -114.0°C. The mixture is then, in a reversible process, brought to a second equilibrium state where the liquid:solid ratio, by mass, is 1:1 at -114.0°C. Calculate the entropy change of the system during this process .

(c) **(5 Marks)** The system is then returned to the initial equilibrium state by an irreversible process (using a Bunsen burner). Calculate the entropy change of the system during this process. Is your answer consistent with the second law of thermodynamics?

Question 2 (10 marks) A brass ring of diameter 10.00 cm at 20.0°C is heated and slipped over an aluminum rod of diameter 10.01 cm at 20.0°C. Assume the average coefficients of linear expansion are constant, and are $\alpha_{Brass} = 2.0 \times 10^{-5}\ \mathrm{K}^{-1}$ and $\alpha_{Al} = 2.4 \times 10^{-5}\ \mathrm{K}^{-1}$. To what temperature must this combination be cooled to separate them?

Question 3 (10 marks) The cartoon in Fig. 1 below correctly shows that icebergs are mostly below water. Given that the density of sea ice is $\rho_i = 917\ \mathrm{kg/m^3}$ and the density of sea water is $\rho_w = 1030\ \mathrm{kg/m^3}$, what fraction of the volume of an iceberg lies below water level?

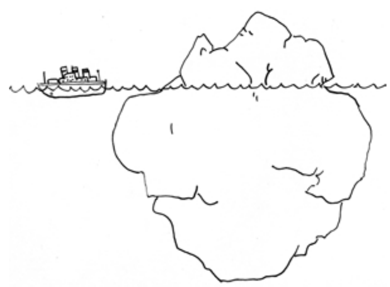

Figure 1: Iceberg cartoon. Most of the iceberg is below water.

Question 4 (25 marks) Figure 2 represents a model for the thermodynamic cycle of the Stirling engine, patented by Scottish clergyman Robert Stirling in 1816. The engine operates by burning fuel externally to warm one of its two cylinders. A fixed quantity of inert gas moves cyclically between the cylinders, expanding in the hot one and contracting in the cold one.

(a) **(15 Marks)** Consider n mol of an ideal monatomic gas being taken once through the cycle in Fig. 2, consisting of two isothermal processes at temperatures $3T_i$ and T_i and two isochoric processes. In terms of n, R, and T_i, determine Q for the complete cycle.

(b) **(10 Marks)** What is the efficiency of the engine? (*Hint:* The heat Q_H transferred into the system happens during steps 1 and 4).

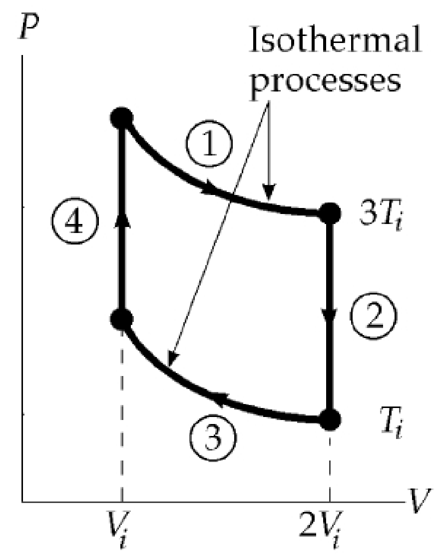

Figure 2: Thermodynamic cycle of the the Stirling engine.

Question 5 (10 marks) Torricelli's Law (1644) preceded Bernoulli's theorem by more than a century. At the time it was a major step forward in the understanding of fluid mechanics. According to Torricelli's law, the fluid that emerges from the bottom of the barrel in Fig. 3 has the same speed it would have obtained by falling freely through the height h of the fluid in the barrel, $v = \sqrt{2gh}$, where g is the acceleration due to gravity. Use Bernoulli's equation to derive Torricelli's law: $v = \sqrt{2gh}$.

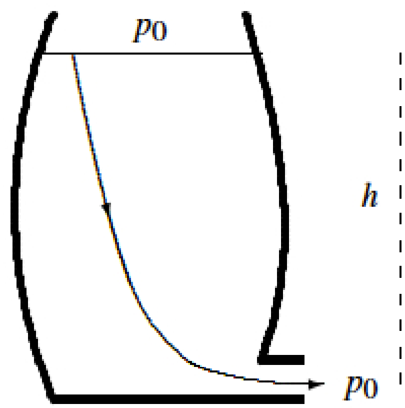

Figure 3: Fluid flowing from the bottom of a barrel.

Question 6 (20 marks) A thin rod with a uniform distribution of positive charge Q is bent into a circle of radius R (Fig. 4). The central perpendicular axis through the ring is the z-axis, with the origin at the center of the ring. The magnitude of the electric field along the axis z is

$$E = \frac{Qz}{4\pi\epsilon_0(z^2 + R^2)^{3/2}} \tag{1}$$

(a) **(2 Marks)** What is the magnitude of the electric field due to the rod at $z = 0$?

(b) **(3 Marks)** What is the magnitude of the electric field due to the rod at $z >> R$?

(c) **(5 Marks)** In terms of R, at what positive value of z is the magnitude of E maximum?

(d) **(10 Marks)** Derive equation (1). The magnitude of the electric charge at P due to segment $dQ = \lambda ds$, where λ is the linear charge density, is $dE = \frac{1}{4\pi\epsilon_0}\frac{dQ}{r^2}$.

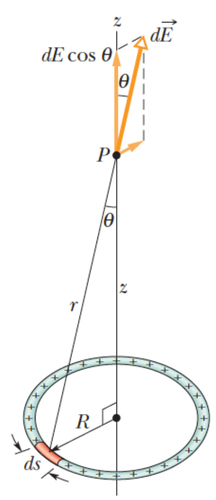

Figure 4: Rod with uniformly distributed charge Q bent into a circle with radius R.