Problem Set No. 2

Due: Wednesday, January 12, 2011

Objective: To understand and perform calculations using fundamental mechanical relations in thermodynamics.

Note: Numerical values for some problems have been changed from those in the book.

Problem 1 (thought problem)

Consider two ways in which you might add energy to a gas inside a piston: (1) compressing the gas to a smaller volume, and (2) heating the gas by raising the temperature of the piston. If you were able to zoom in and watch these two process at the molecular level, both would involve the transfer of kinetic energy due to collisions between moving and vibrating atoms in the piston with atoms in the gas (similar to billiard balls). What, therefore, is the difference between compression and heating at the molecular level?

Problem 2 (*Smith, van Ness, Abbott, 1.8, page 16)*

The reading on a mercury manometer at 70 °F (open to the atmosphere at one end) is 23.1 inches. The local acceleration of gravity is 32.243 $ft \cdot s^{-2}$. Atmospheric pressure is 29.86 in. Hg. What is the absolute pressure in psia being measured? The density of mercury at 70 °F is 13.534 $g \cdot cm^{-3}$.

Problem 3 (*Smith, van Ness, Abbott, 1.16, page 17)*

A gas is confined in a 0.55 m diameter cylinder by a piston, on which rests a weight. The mass of the piston and weight together is 120 kg. The local acceleration of gravity is 9.813 $m \cdot s^{-2}$, and atmospheric pressure is 101.57 kPa.

(a) What is the force in newtons exerted on the gas by the atmosphere, the piston, and the weight, assuming no friction between the piston and cylinder?

(b) What is the pressure of the gas in kPa?

(c) If the gas in the cylinder is heated, it expands, pushing the piston and weight upward. If the piston and weight are raised 0.70 m, what is the work done by the gas in kJ? What is the change in potential energy of the piston and weight?

Problem 4

According to Edmunds.com, the 2011 Toyota Prius has a mass of 3042 lb_m. If a Prius is traveling at 40 mph, what is its kinetic energy, in kJ? Assume that the Prius is brought to a stop and 60% of its kinetic energy is recovered and deposited in the battery pack, with the remaining being lost to friction. If this same energy can then be extracted from the battery pack at 80% efficiency, accelerating the vehicle, what will be its final speed, in mph?

Problem 5 (*Smith, van Ness, Abbott, 1.25ab, page 19)*

Chemical-plant equipment costs rarely vary in proportion to (i.e., linearly with) size. In the simplest case, cost C varies with size S according to the *allometric* equation

$$C = \alpha S^{\beta}$$

The size of the exponent β is typically between 0 and 1. For a wide variety of equipment types, it is approximately 0.6.

(a) For $0 < \beta < 1$, show that cost per *unit size* decreases with increasing size. ("Economy of scale.")

(b) Consider the case of a spherical storage tank. The size is commonly measured by internal volume V_i^t. Show that $\beta = 2/3$. On what parameters or properties would you expect the quantity α to depend?

Problem 6 (*Smith, van Ness, Abbott, 2.2, page 56)*

An insulated container filled with 20 kg of water at 22 °C is fitted with a stirrer, which is made to turn by gravity acting on a weight of mass 32 kg. The weight falls slowly through a distance of 4 m in driving the stirrer. Take the heat capacity of the container to be equivalent to 5 kg of water (C_P = 4.18 kJ$\cdot$kg$^{-1}\cdot$°C^{-1}) and the local acceleration of gravity to be 9.8 m$\cdot$s^{-2}. Determine:

(a) the amount of work done on the water-container system,

(b) the internal-energy change of the water-container system,

(c) the final temperature of the water-container system,

(d) the amount of heat that must be removed from the water-container system to return it to its initial temperature,

(e) the total energy change of the universe because of (1) the process of lowering the weight, (2) the process of cooling the water-container system back to its initial temperature, and (3) both processes together.