

STUDENT #: \_\_\_\_\_

NAME: \_\_\_\_\_

**ASSIGNMENT 2: Pressure, Ideal Gas Equation,  
First Law of Thermodynamics, Heat Transport.  
Calorimetry**

Released: Sept 23,

Due: Sept 30

6PM

**1** Evangelista Torricelli was the first person to realize that we live at the bottom of an ocean of air. He correctly surmised that the pressure of our atmosphere is attributable to the weight of the air. The density of air at 0°C at the Earth's surface is 1.29 kg/m<sup>3</sup>. The density decreases with increasing altitude (as the atmosphere thins). On the other hand, if we assume that the density is constant at 1.29 kg/m<sup>3</sup> up to some altitude  $h$ , and zero above that altitude, then  $h$  would represent the depth of the ocean of air. Use this model to determine the value of  $h$  that gives a pressure of 1.00 atm at the surface of the Earth. Would the peak of Mount Everest rise above the surface of such an atmosphere?

$$P = \rho gh$$

$$1.013 \times 10^5 = 1.29(9.80)h$$

$$h = \boxed{8.01 \text{ km}}$$

$$\text{For Mt. Everest, } 29\,300 \text{ ft} = 8.88 \text{ km}$$

Yes

**2** a) In state-of-the-art vacuum systems, pressures as low as 10<sup>-9</sup> Pa are being attained. Calculate the number of molecules in a 1.00-m<sup>3</sup> vessel at this pressure if the temperature is 27.0°C.

$$a) N = \frac{PVN_A}{RT} = \frac{(10^{-9} \text{ Pa})(1.00 \text{ m}^3)(6.02 \times 10^{23} \text{ molecules/mol})}{(8.314 \text{ J/K} \cdot \text{mol})(300 \text{ K})} = \boxed{2.41 \times 10^{11} \text{ molecules}}$$

b) A copper wire and a lead wire are joined together, end to end. The compound wire has an effective coefficient of linear expansion of  $20.0 \times 10^{-6} (\text{°C})^{-1}$ . What fraction of the length of the compound wire is copper?

b) The effective coefficient is defined by  $\Delta L_{\text{total}} = \alpha_{\text{effective}} L_{\text{total}} \Delta T$  where  $\Delta L_{\text{total}} = \Delta L_{\text{Cu}} + \Delta L_{\text{Pb}}$  and  $L_{\text{total}} = L_{\text{Cu}} + L_{\text{Pb}} = xL_{\text{total}} + (1-x)L_{\text{total}}$ .

Then by substitution

$$\alpha_{\text{Cu}} L_{\text{Cu}} \Delta T + \alpha_{\text{Pb}} L_{\text{Pb}} \Delta T = \alpha_{\text{eff}} (L_{\text{Cu}} + L_{\text{Pb}}) \Delta T$$

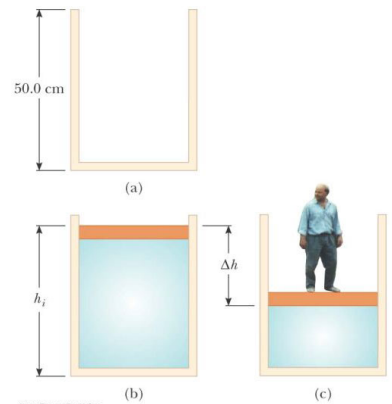
$$\alpha_{\text{Cu}} x + \alpha_{\text{Pb}} (1-x) = \alpha_{\text{eff}}$$

$$(\alpha_{\text{Cu}} - \alpha_{\text{Pb}})x = \alpha_{\text{eff}} - \alpha_{\text{Pb}}$$

$$x = \frac{20 \times 10^{-6} \text{ 1/°C} - 29 \times 10^{-6} \text{ 1/°C}}{17 \times 10^{-6} \text{ 1/°C} - 29 \times 10^{-6} \text{ 1/°C}} = \frac{9}{12} = \boxed{0.750}$$

**3** cylinder that has a 40.0-cm radius and is 50.0 cm deep is filled with air at 20.0°C and 1.00 atm. A 20.0-kg piston is now lowered into the cylinder, compressing the air trapped inside (Fig. P19.68b). Finally, a 75.0-kg man stands on the piston, further compressing the air, which remains at 20°C (Fig. P19.68c). (a) How far down ( $\Delta h$ ) does the piston move when the man steps onto it? (b) To what temperature should the gas be heated to raise the piston and man back to  $h_i$ ?

PROVIDE THE FULL SOLUTION ON OPPOSITE PAGE



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**ASSIGNMENT 2:CONT**

- 4 a) A water heater is operated by solar power. If the solar collector has an area of  $6.00 \text{ m}^2$ , and the intensity delivered by sunlight is  $550 \text{ W/m}^2$ , how long does it take to increase the temperature of  $1.00 \text{ m}^3$  of water from  $20.0^\circ\text{C}$  to  $60.0^\circ\text{C}$ ?
- b) The surface of certain star n has a temperature of about  $15\,800 \text{ K}$ . The radius of the star is  $9 \times 10^8 \text{ m}$ . Calculate the total energy radiated by this star each second. Assume that the emissivity is  $0.995$ .

A) The rate of collection of energy is  $P = 550 \text{ W/m}^2 (6.00 \text{ m}^2) = 3\,300 \text{ W}$ . The amount of energy required to raise the temperature of  $1\,000 \text{ kg}$  of water by  $40.0^\circ\text{C}$  is:

$$Q = mc\Delta T = 1\,000 \text{ kg}(4\,186 \text{ J/kg}\cdot^\circ\text{C})(40.0^\circ\text{C}) = 1.67 \times 10^8 \text{ J}$$

Thus,  $P\Delta t = 1.67 \times 10^8 \text{ J}$  or  $\Delta t = \frac{1.67 \times 10^8 \text{ J}}{3\,300 \text{ W}} = \boxed{50.7 \text{ ks}} = 14.1 \text{ h}$ .

ANS B

$$B) P = \sigma A \epsilon T^4 = (5.669\,6 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4) \left[ 4\pi (6.96 \times 10^8 \text{ m})^2 \right] (0.965)(5\,800 \text{ K})^4 P = \boxed{3.77 \times 10^{26} \text{ W}}$$

- 5 At high noon, the Sun delivers  $1\,000 \text{ W}$  to each square meter of a blacktop road. If the hot asphalt loses energy only by radiation, what is its equilibrium temperature?

We treat the earth below is an insulator. The square meter must radiate in the infrared as much energy as it absorbs,  $P = \sigma A \epsilon T^4$ . Assuming that  $\epsilon = 1.00$  for blackbody blacktop:

$$1\,000 \text{ W} = (5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4) (1.00 \text{ m}^2) (1.00) T^4 \quad T = (1.76 \times 10^{10} \text{ K}^4)^{1/4} = \boxed{364 \text{ K}}$$

(You can cook an egg on it.)

- 6 A  $2 \text{ kg}$  of ice at  $-20^\circ\text{C}$  is added to  $5 \text{ kg}$  of steam at  $400^\circ\text{C}$ . answer the following questions:

a) What is the phase of the system of ice + steam if no heat escaped from it.

b) What is the final temperature when the equilibrium is established

(use the opposite side of this page to provide the solution)

CHECK THE CLASS NOTES FOR THE DISCUSSION OF THIS TYPE OF PROBLEM

I) It takes  $1586400 \text{ J}$  to 1) warm up the ice to  $0^\circ\text{C}$ , 2) melt it, 3) warm up the water to  $100^\circ\text{C}$ .

II) When the steam cools off to  $100^\circ\text{C}$  it can give off  $2925000 \text{ J}$  of heat.

Since  $2925000 > 15846400 \text{ J}$  the  $2 \text{ kg}$  water from the ice will be brought to  $100^\circ\text{C}$  while the steam will not cool all the way to  $100^\circ\text{C}$ .

The remaining heat  $2925000 \text{ J} - 1586400 \text{ J} = 1338600 \text{ J}$  will be used to convert  $0.591 \text{ kg}$  of water to steam.

**Final state of this system is  $1.409 \text{ kg}$  of water at  $100^\circ\text{C}$  and  $5.591 \text{ kg}$  of steam all at  $100^\circ\text{C}$ .**

### Problem 3

With piston alone:

$$T = \text{constant, so } PV = P_0V_0$$

$$\text{or } P(Ah_i) = P_0(Ah_0)$$

$$\text{With } A = \text{constant, } P = P_0\left(\frac{h_0}{h_i}\right)$$

$$\text{But, } P = P_0 + \frac{m_p g}{A}$$

where  $m_p$  is the mass of the piston.

$$\text{Thus, } P_0 + \frac{m_p g}{A} = P_0\left(\frac{h_0}{h_i}\right)$$

which reduces to

$$h_i = \frac{h_0}{1 + \frac{m_p g}{P_0 A}} = \frac{50.0 \text{ cm}}{1 + \frac{20.0 \text{ kg}(9.80 \text{ m/s}^2)}{1.013 \times 10^5 \text{ Pa}[\pi(0.400 \text{ m})^2]}} = 49.81 \text{ cm}$$

With the man of mass  $M$  on the piston, a very similar calculation (replacing  $m_p$  by  $m_p + M$ ) gives:

$$h' = \frac{h_0}{1 + \frac{(m_p + M)g}{P_0 A}} = \frac{50.0 \text{ cm}}{1 + \frac{95.0 \text{ kg}(9.80 \text{ m/s}^2)}{1.013 \times 10^5 \text{ Pa}[\pi(0.400 \text{ m})^2]}} = 49.10 \text{ cm}$$

Thus, when the man steps on the piston, it moves downward by

$$\Delta h = h_i - h' = 49.81 \text{ cm} - 49.10 \text{ cm} = 0.706 \text{ cm} = \boxed{7.06 \text{ mm}}.$$

$$(b) \quad P = \text{const, so } \frac{V}{T} = \frac{V'}{T_i} \quad \text{or} \quad \frac{Ah_i}{T} = \frac{Ah'}{T_i}$$

$$\text{giving } T = T_i\left(\frac{h_i}{h'}\right) = 293 \text{ K}\left(\frac{49.81}{49.10}\right) = \boxed{297 \text{ K}} \quad (\text{or } 24^\circ\text{C})$$

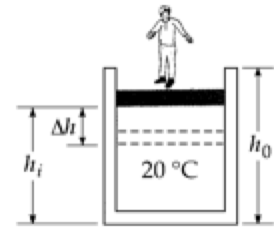


FIG. P19.68