

ASSIGNMENT 2:
Pressure, Ideal Gas
Equation, First Law of
Thermodynamics,
Heat Transport. Calorimetry
Released: Sept 21,

UNIVERSITY OF OTTAWA
 Principles of Physics
 PHY1321/31 Fall 2018
 Dr. A. Czajkowski

Due: Sept 28 6PM

STUDENT #: _____

NAME: _____

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/m³. 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/m³ 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?

$$P = \rho gh. \quad 1.013 \times 10^5 = 1.29(9.80)h$$

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

$$\text{For Mt. Everest, } 29300 \text{ ft} = 8.88 \text{ km.} \quad \text{Yes}$$

- 2 a) In state-of-the-art vacuum systems, pressures as low as 10⁻¹⁰ Pa are being attained. Calculate the number of molecules in a 1.00-m³ vessel at this pressure if the temperature is 21.0°C.
 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 23.0 × 10⁻⁶ (°C)⁻¹. What fraction of the length of the compound wire is copper?

$$\text{a) } N = \frac{PVN_A}{RT} = \frac{(10^{-10} \text{ Pa})(1.00 \text{ m}^3)(6.02 \times 10^{23} \text{ molecules/mol})}{(8.314 \text{ J/K.mol})(294 \text{ K})}$$

$$= 2.46 \times 10^{10} \text{ molecules}$$

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 $L_{\text{total}} = L_{\text{Cu}} + L_{\text{Pb}} = L_{\text{total}} = L_{\text{Cu}} + L_{\text{Pb}}$
 $= xL_{\text{total}} + (1-x)L_{\text{total}}$

Then by substitution,

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

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

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

$$x = \frac{23.0 \times 10^{-6} (\text{C})^{-1} - 29 \times 10^{-6} (\text{C})^{-1}}{17 \times 10^{-6} (\text{C})^{-1} - 29 \times 10^{-6} (\text{C})^{-1}} = \frac{6}{12} = 0.5$$

3 A diving bell in the shape of a cylinder with a height of 2.70 m is closed at the upper end and open at the lower end. The bell is lowered from air into sea water ($\rho = 1.033 \text{ g/cm}^3$). The air in the bell is initially at 25.0°C. The bell is lowered to a depth (measured to the bottom of the bell) of 90.0 m. At this depth the water temperature is 4.0°C, and the bell is in thermal equilibrium with the water.

- (a) How high does sea water rise in the bell? (b) To what minimum pressure must the air in the bell be raised to expel the water that entered?

PROVIDE THE FULL SOLUTION ON THE OPPOSITE PAGE

ASSIGNMENT 2:CONT

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- 4 a) A water heater is operated by solar power. If the solar collector has an area of 8.00 m^2 , and the intensity delivered by sunlight is 550 W/m^2 , how long does it take to increase the temperature of 1.00 m^3 of water from 17.0°C to 62.0°C ?

Ans: The rate of collection of energy is $P = 550 \text{ W/m}^2 * 8.00 \text{ m}^2 = 4400 \text{ W}$. The amount of energy required to raise the temperature of 1000 kg of water by 45.0°C is:

$$Q = mc\Delta T = 1000 \text{ kg}(4186 \text{ J/Kg} \cdot ^\circ\text{C})(45^\circ\text{C}) = 1.88 * 10^8 \text{ J}$$

Thus,

$$P\Delta t = 1.88 * 10^8 \text{ or } \Delta t = \frac{1.88 * 10^8 \text{ J}}{4400 \text{ W}} = 42.8 \text{ ks} = 11 \text{ h}$$

- 4 b) The surface of certain star n has a surface temperature of about 5800 K . The radius of the star is $9 \times 10^8 \text{ m}$. Calculate the total energy radiated by this star in each second. Assume that the emissivity is 0.995 .

$$\text{Ans: } P = \sigma AeT^4 = (5.669 * 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)[4\pi(9 * 10^8)^2](0.995)(5800\text{K})^4 = 6.50 * 10^{26} \text{ W}$$

- 5 At high noon, the Sun delivers 1100 W to each square meter of a blacktop road. If the hot asphalt loses energy only by radiation, what is its equilibrium temperature?

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

$$1100 \text{ W} = (5.67 * 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)(1.00)T^4 \text{ or } T = (1.94 * 10^{10} \text{ K}^4)^{1/4} = 373 \text{ K}$$

(You can cook an egg on it.)

- 6 A 2 kg of ice at -20°C is added to 3 kg of steam at 140°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
CHECK THE CLASS NOTES FOR THE DISCUSSION OF THIS TYPE OF PROBLEM
(use the opposite side of this page to provide the detailed solution)

Ans 6

CONSTANTS USED:

Specific heat of water:	4186
Specific Heat of ice	2030
Specific Heat of steam	1950
Latent heat of fusion	33400
Latent heat of evaporation:	2264760

To warm up the ice to 0	one needs:	81200J
To melt the ice	one needs:	668000J
To warm up the resulting water from 0 to 100	one needs:	837200J
TOTAL TO GET ICE TO BOILING POINT:		1586400J

By cooling down the steam from 140 to 100	one gets	234000J
By converting the steam to water at 100	one gets	6794280J
TOTAL TO GET ICE TO WATER AT 100		7028280

- It takes 1,586,400 J to 1) warm up the ice to 0C, 2) melt it, and 3) heat it to 100C.
- When the steam cools off to 100C it releases 234,000 J heat. This is not enough to affect the ice transformations as outlined in (a)!
- The conversion of steam to water has to be tapped to, in order to finish melting of the ice and bringing the resulting 2kg water to 100 degrees.

We will only need 1586400J out of 7028280J available from steam.

What it means is this:

We have "unused (7028280J-1586400J) of energy from steam to water conversion. This unused heat corresponds to 2.403kg of steam! ($Q=Lm$)

ANSWER:

a) Final state of the system is a mixture of water and steam:

$$\text{Mass of steam at } 100\text{C} = 3\text{kg} - 0.60\text{kg} = 2.40 \text{ kg.}$$

$$\text{Mass of water } 100\text{C} = 2\text{kg} + 0.60 \text{ kg} = 2.60 \text{ kg.}$$

b) The final temperature is 100 C.

Question 3 answer:

(diagram of this situation was provided during the lecture)

a) Initially when in air,

$$P_i = P_{atm} = 1.01 * 10^5 Pa. \quad T_i = 273 + 25 = 298K. \quad V_i = A(l - x)$$

The water enters the bell and fills it up to level x from the bottom of the bell!

Once the bell is lowered the pressure at the h-x depth is given by;

$$P_f = P_{atm} + \rho_{water}g(h - x) = 1.01 * 10^5 Pa + \frac{1033kg}{m^3} * \frac{9.88m}{s^2} * (90 - x) m.$$

Where x be the height of water from the bottom of the jar. Since it is assumed that no amount of air escapes we have the following relation from the ideal gas equation,

$$\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$$

$$(P_{atm}V)/298 = (P_{at90m}V_2)/(273 + 4).$$

$$\text{or, } P_{atm} * \frac{Ah'}{298} = \left(P_{atm} + \frac{1033kg}{m^3} * \frac{9.80m}{s^2} * (90 - x) \right) * \frac{A(l-x)}{277}.$$

$$\text{or, } 2.70 * \frac{277}{298} = \left(1 + 1033 * \frac{9.80(90-x)}{P_{atm}} \right) (2.70 - x)$$

Rearranging, we get the quadratic equation,

$$\text{or, } 0.10x^2 - 10.29x + 24.54 = 0.$$

Solving for x,

$$\text{We get, } x = 100.46m, 2.44m.$$

Since 100.46m for the x is inadmissible ($l < x$)!

The correct answer is $x=2.44m$

ANSWER A At the depth of 90m, the water will rise up to the height of 2.44m

ANSWER B: To lower the height of water in the diving bell the increase in pressure should be,

$$\Delta P = \rho_{water}gx = \frac{1033kg}{m^3} * \frac{9.80m}{s^2} * 2.44m = 2.47 * 10^4 Pa.$$