Assignment #6

Physics 2 Spring 2020
Instructor: Prof. Dirk Bouwmeester
Due: 05/10/20 5pm PST
Comments: Each problem is worth three points. If the problem has multiple parts, each part is worth the same points.

1 Land vs Ocean Temperature

In coastal regions in the winter, the temperature over the land is generally colder than the temperature over the nearby ocean; in the summer, the reverse is usually true. Explain. (Hint: The specific heat of soil is only 0.2–0.8 times as great as that of water.)

Soil 0.2 – 0.8 times as great as water,
less energy needed to heat up
Land Temp > Ocean Temp summer, in winter, soil drops easier, so soil colder

2 Some Temperature Records

Convert the following Celsius temperatures to Fahrenheit: (a) -62.8°C the lowest temperature ever recorded in North America (February 3, 1947, Snag, Yukon); (b) 56.7°C the highest temperature ever recorded in the United States (July 10, 1913, Death Valley, California); (c)31.1°C the world's highest average annual temperature (Lugh Ferrandi, Somalia).

a) $-81.04°F$
b) $134.06°F$
c) $87.98°F$

3 A Constant-Volume Gas Thermometer

An experimenter using a gas thermometer found the pressure at the triple point of water (0.01°C) to be 4.8×10^4 Pa and the pressure at the normal boiling point (100°C)to be 6.50×10^4 Pa. (a) Assuming that the pressure varies linearly with temperature, use these two data points to find the Celsius temperature at which the gas pressure would be zero (that is, find the Celsius temperature of absolute zero). (b) Does the gas in this thermometer obey precisely

$$\frac{T_2}{T_1} = \frac{p_2}{p_1} \tag{1}$$

If this equation were precisely obeyed and the pressure at $100°$ C were 6.50×10^4 Pa, what pressure would the experimenter have measured at $0.01°$ C? (As we will learn in Section 18.1, Eq. (1) is accurate only for gases at very low density.)

a) $G = \frac{\Delta P}{\Delta T} = \frac{(6.5-4.8)\times 10^4}{(100-0.01)} \approx 170$

$y = kx + c, \quad \therefore x = -282°C$

b) Does not

c) $P_1 = \frac{6.5\times 10^4 \times 273}{373} = 4.75 \times 10^4$ pa

4 Area Expansion

(a) If an area measured on the surface of a solid body is A_0 at some initial temperature and then changes by ΔA when the temperature changes by ΔT, show that

$$\Delta A = (2\alpha)A_0\Delta T \tag{2}$$

$A = L_a \times L_b$, $L_a = L_1(1+\alpha\Delta T)$ $L_b = L_2(1+\alpha\Delta T)$

$A = A_0(1+2\alpha\Delta T)$

$\Delta A = A - A_0 = 2\alpha A_0 \Delta T$

where α is the coefficient of linear expansion. (b) A circular sheet of aluminum is 50.0 cm in diameter at 12°C. By how much does the area of one side of the sheet change when the temperature increases to 25.0°C?

$\Delta A = \pi(0.25)^2 \times 2\alpha \times (25-12)$

$= 1.225 \times 10^{-4}\ m^2$

5 A Bullet

A 20.0 g bullet traveling horizontally at 760 m/s passes through a tank containing 13.5 kg of water and emerges with a speed of 534 m/s. What is the maximum temperature increase that the water could have as a result of this event?

$$\Delta T = \frac{\frac{1}{2} \times \frac{20}{1000}(760^2 - 534^2)}{13.5 \times 4.19 \times 10^3}$$

$$\approx 0.0517°c$$

6 Bicycling on a Warm Day

If the air temperature is the same as the temperature of your skin (about 30°C), your body cannot get rid of heat by transferring it to the air. In that case, it gets rid of the heat by evaporating water (sweat). During bicycling, a typical 60-kg person's body produces energy at a rate of about 500 W due to metabolism, 80% of which is converted to heat. (a) How many kilograms of water must the person's body evaporate in an hour to get rid of this heat? The heat of vaporization of water at body temperature is 2.42×10^6 J/kg. (b) The evaporated water must, of course, be replenished, or the person will dehydrate. How many 750-mL bottles of water must the bicyclist drink per hour to replenish the lost water? (Recall that the mass of a liter of water is 1.0 kg.)

$Q = 500 \times 3600 \times 0.8 = 1.44 \times 10^6$

$\frac{1.44 \times 10^6}{2.42 \times 10^6} \approx 0.595$ kg

0.595 kg of water => 595 mL < 750 mL

0.8 bottle per hour

7 The Sizes of Stars

The hot glowing surfaces of stars emit energy in the form of electromagnetic radiation. It is a good approximation to assume $e = 1$ for these surfaces. Find the radii of the following stars (assumed to be spherical): (a) Rigel, the bright blue star in the constellation Orion, which radiates energy at a rate of 2.7×10^{32} W and has surface temperature 11,000 K; (b) Procyon B (visible only using a telescope), which radiates energy at a rate of 2.1×10^{23} W and has surface temperature 10,000 K. (c) Compare your answers to the radius of the earth, the radius of the sun, and the distance between the earth and the sun. (Rigel is an example of a *supergiant* star, and Procyon B is an example of a *white dwarf* star.)

$H = Ae\sigma T^4$ a) 1.608×10^{11}

b) 5.43×10^6

$R = \frac{1}{T^2}\sqrt{\frac{H}{4\pi\sigma}}$ c) $5.43 \times 10^6 \approx 6.38 \times 10^6 < 6.96 \times 10^8 \ll 1.5 \times 10^{11} \approx 1.608 \times 10^{11}$

8 Varying Temperature

(a) A spherical shell has inner and outer radii a and b, respectively, and the temperatures at the inner and outer surfaces are T_2 and T_1, respectively. The thermal conductivity of the material of which the shell is made is k. Derive an equation for the total heat current through the shell. (b) Derive an equation for the temperature variation within the shell in part (a); that is, calculate T as a function of r, the distance from the center of the shell. (c) A hollow cylinder has length L, inner radius a, and outer radius b, and the temperatures at the inner and outer surfaces are T_2 and T_1, respectively. (The cylinder could represent an insulated hot-water pipe, for example.) The thermal conductivity of the material of which the cylinder is made is k. Derive an equation for the total heat current through the walls of the cylinder.

$\int dr \frac{H}{A} = \int k \, dt$

$\frac{H}{4\pi}\left(\frac{1}{a} - \frac{1}{b}\right) = k\Delta T$

$H = \frac{4k\pi ab(T_2 - T_1)}{b - a}$

$\frac{dT}{dr} = \frac{B}{r^2}$, $B = \frac{H}{4\pi k}$

$\int dt = \int \frac{B}{r^2} dr$

$T_1 - R_2 = B\left(\frac{1}{a} - \frac{1}{b}\right)$

$T - T_2 = B\left(\frac{1}{a} - \frac{1}{r}\right)$

$T = T_2 - (T_2 - T_1)\left(\frac{r-a}{b-a}\right)\left(\frac{b}{r}\right)$

$\int H = \int k(2\pi r L)\frac{dT}{dr}$

$\frac{H}{2\pi r}\ln\left(\frac{b}{a}\right) = kL(T_2 - T_1)$

$H = \frac{2\pi kL(T_2 - T_1)}{\ln(b/a)}$