Physics

Unit 6: Temperature, Heat, and Thermodynamics

1. *Meanings and concepts of terms like thermal expansion, equilibrium, condensation, evaporation, sublimation, freezing, melting, humidity, heat, calorimeter, convection, conduction, radiation, blackbody radiator, thermodynamics, heat engine, heat pump, Carnot engine, entropy*
2. *The coefficient of linear expansion of aluminum is* 2.3×10^{-6} */C°. A circular hole in an aluminum plate is 10 cm in diameter at 10 °C. What is the diameter of the hole if the temperature of the plate is raised to 100 °C?*
3. *A sample of a monatomic ideal gas is originally at 20 °C. What is the final temperature of the gas if both the pressure and volume are quadrupled?*
4. *Late on an autumn day, the relative humidity is 60% and the temperature in 30 °C. What will the relative humidity be that evening when the temperature has dropped to 10 °C, assuming constant water vapor density?*
5. *A 5-kg lead shot is heated to 200 °C and dropped into an ideal calorimeter containing 10 kg of water initially at 20.0 °C. What is the final equilibrium temperature of the lead shot? The specific heat capacity of lead is 128 J/(kg·C°); and the specific heat of water is 4186 J/(kg·C°).*
6. *What is the minimum amount of energy required to completely melt a 5-kg lead brick which has a starting temperature of 20 °C? The melting point of lead is 328 °C. The specific heat capacity of lead is 128 J/(kg·C°); and its latent heat of fusion is 23200 J/kg.*
7. *A blue supergiant star has a radius of* 5×10^{10} *m. The spherical surface behaves as a blackbody radiator. If the surface temperature is* 5×10^{4} *K, what is the rate at which energy is radiated from the star?*
8. *At what rate is heat lost through a 5 m × 10 m rectangular glass windowpane that is 0.5 cm thick when the inside temperature is 20 °C and the outside temperature -5 °C? The thermal conductivity for glass is 0.80 W/(m·C°).*
9. *A system containing an ideal gas at a constant pressure of* 5×10^{5} *Pa gains 100 J of heat. During the process, the internal energy of the system increases by 500 J. What is the change in volume of the gas?*
10. *An engine is used to lift a 5000 kg truck to a height of 2 m at constant speed. In the lifting process, the engine received* 5×10^{5} *J of heat from the fuel burned in its interior. What is the efficiency of the engine?*
11. *A Carnot heat engine is to be designed with an efficiency of 60%. If the low temperature reservoir is 20 °C, what is the temperature of the "hot" reservoir?*
12. *If the coefficient of performance for a refrigerator is 6 and 1000 J of work are done on the system, how much heat is rejected to the room?*
13. *A 20-kg sample of steam at 100.0 °C condenses to water at 100.0 °C. What is the entropy change of the sample if the heat of vaporization of water is* 2.26×10^{6} *J/kg?*

2. $\alpha = 2.3 \times 10^{-6}/C°, d_1 = 0.10\ m, T_1 = 10\ °C, T_2 = 100\ °C$
$\Delta L = \alpha L \Delta T$
$\Delta L = (2.3 \times 10^{-6}\ /C°)(0.10\ m)(100\ °C - 10\ °C)$
$\Delta L = 2.07 \times 10^{-5}\ m$
$d_2 = 0.10\ m + 2.07 \times 10^{-5}\ m = \mathbf{1.0002 \times 10^{-1}\ m}$

3. $T_1 = 20\ °C = 293.15\ K, P_2 = 4P_1, V_2 = 4V_1$
$PV = nRT$
$\frac{PV}{T} = nR$
since nR is constant
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
$\frac{P_1V_1}{293.15\ K} = \frac{(4P_1)(4V_1)}{T_2}$
$\frac{1}{293.15\ K} = \frac{16}{T_2}$
$T_2 = \mathbf{4690\ K = 4417\ °C}$

4. $\%\ hum_1 = 60\ \%, T_1 = 30\ °C, T_2 = 10\ °C$
$\%\ relative\ humidity$
$= \frac{vapor\ density}{saturation\ vapor\ density} \times 100\%$
$60\ \% = \frac{vapor\ density}{30.4 \frac{g}{m^3}} \times 100\%$
$vapor\ denstiy = 18.24 \frac{g}{m^3}$
$\%\ humid = \frac{18.24 \frac{g}{m^3}}{9.4 \frac{g}{m^3}} \times 100\%$
$\%\ humidity = \mathbf{194}\ \%$
This can't really happen. It started raining and the humidity stayed at 100%.

5. $m_l = 5\ kg, T_l = 200\ °C, m_w = 10\ kg, T_w = 20°C, c_l = 128 \frac{J}{kg \cdot C°}, c_w = 4186 \frac{J}{kg \cdot C°}$
$Q = mc\Delta T$
$-Q_l = Q_w$
$-(5\ kg)\left(128 \frac{J}{kg \cdot C°}\right)(T_f - 200°C)$
$= (10\ kg)\left(4186 \frac{J}{kg \cdot C°}\right)(T_f - 20\ °C)$
$-640 \frac{J}{C°} T_f + 128000\ J = 41860 \frac{J}{C°} T_f - 837200\ J$
$-42500 \frac{J}{C°} T_f = -965200\ J$
$T_f = \mathbf{22.7\ °C}$

6. $m = 5\ kg, T_0 = 20\ °C, T_{melt} = 328\ °C, c = 128 \frac{J}{kg \cdot C°}, L_f = 23200 \frac{J}{kg}$
$Q = mc\Delta T$
$Q = (5\ kg)\left(128 \frac{J}{kg \cdot C°}\right)(328\ °C - 20\ °C)$
$Q = 197120\ J$
$Q_{melt} = mL_f$
$Q_{melt} = (5\ kg)\left(23200 \frac{J}{kg}\right) = 116000\ J$
$Q_{tot} = 197120\ J + 116000\ J = \mathbf{313120\ J}$

7. $r = 5 \times 10^{10} m, T = 5 \times 10^4 K, e = 1$
$\frac{Q}{t} = \sigma e A T^4$
$\frac{Q}{t} = \left(5.67 \times 10^{-8} \frac{J}{s \cdot m^2 \cdot K^4}\right)(1)(4\pi(5 \times 10^{10}\ m)^2)(5 \times 10^4\ K)^4$
$\frac{Q}{t} = \mathbf{1.11 \times 10^{34} \frac{J}{s}}$

8. $A = (5\ m)(10\ m) = 50\ m^2, d = 0.005\ m, T_2 = -5\ °C, T_1 = 20\ °C, k = 0.80 \frac{W}{m \cdot C°}$
$\frac{Q}{t} = \frac{kA(T_2 - T_1)}{d}$
$\frac{Q}{t} = \frac{\left(0.80 \frac{W}{m \cdot C°}\right)(50\ m^2)(-5\ °C - 20\ °C)}{0.005\ m}$
$\frac{Q}{t} = \mathbf{-200000 \frac{J}{s}}$

9. $P = 5 \times 10^5\ Pa, Q = 100\ J, \Delta U = 500\ J$
$\Delta U = Q - W$
$500\ J = 100\ J - W$
$W = -400\ J$
$W = P\Delta V\ (isobaric\ process)$
$-400\ J = (5 \times 10^5\ Pa)\Delta V$
$\Delta V = \mathbf{-0.0008\ m^3}$

10. $m = 5000\ kg, h = 2\ m, Q = 5 \times 10^5\ J$
$Eff = \frac{W}{Q_h}$
$Eff = \frac{(5000\ kg)\left(9.8 \frac{m}{s^2}\right)(2\ m)}{5 \times 10^5\ J} = \mathbf{0.196}$

11. $Eff_C = 0.60, T_c = 20\ °C = 293.15\ K$
$Eff_C = 1 - \frac{T_c}{T_h}$
$0.60 = 1 - \frac{293.15\ K}{T_h}$
$-0.40 = -\frac{293.15\ K}{T_h}$
$T_h = \frac{-293.15\ K}{-0.40} = \mathbf{732.88\ K = 439.73\ °C}$

12. $COP_{ref} = 6, W = 1000\ J$
$COP_{ref} = \frac{Q_c}{W}$
$6 = \frac{Q_c}{1000\ J}$
$Q_c = \mathbf{6000\ J}$

13. $m = 20\ kg, T = 100\ °C = 373.15\ K, L_v = 2.26 \times 10^6 \frac{J}{kg}$
$\Delta S = \frac{Q}{T}$
$\Delta S = \frac{-(20\ kg)\left(2.26 \times 10^6 \frac{J}{kg}\right)}{373.15\ K} = \mathbf{-121000 \frac{J}{K}}$