1. A constant volume gas thermometer is calibrated in dry ice (-80^{0}C, 0.900 atm) and in boiling ethyl alcohol (78^{0}C, 1.635 atm).

- What value of absolute zero does the calibration yield?

$$T = aP + B$$
$$a = \frac{\Delta T}{\Delta P} = 215.0\ {}^0C/atm$$
$$b = T_0 = T - aP = -273.5^0C$$

- What pressures would be found at the critical points of water?

$$P = \frac{T - b}{a}$$

This yields 1.27 atm @ freezing and 1.74 atm @ boiling.

2. A constant volume gas thermometer registers a pressure of 50mm mercury @ 450K.

- What is the pressure at the H_2O triple point?

$$Pv = nRT \Rightarrow \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \text{ (Boyle's Law)}$$

In a constant volume process:

$$V_1 = V_2 \therefore P_1T_2 = P_2T_1 \therefore P_2 = \frac{P_1T_2}{T_1} = \frac{(50mm)(273.16K)}{450K} = 30.4mm$$

- What is the temperature when the pressure reads 2mm of mercury?

$$T_2 = \frac{P_2T_1}{P_1} = \frac{(2mm)(450K)}{50mm} = 18K$$

3. **The coefficient of expansion for carbon tetrachloride is 5.81 × 10^{-4} $^0C^{-1}$. If a 50 gallon steel drum is filled with carbon tetrachloride when the temperature is 10^0C, how much spills out of the drum when the temperature is 30^0C?**

$$\beta = 5.81 \times 10^{-4}\,{}^0C^{-1}$$
$$\Delta T = 20^0 C$$
$$V_0 = 50gal$$

$$\Delta V = \beta V_0 \Delta T = 0.548gal$$

4. **The concrete sections of a highway are poured and cured at 10^0C. What minimum spacing should be left between the slabs to eliminate buckling at a maximum temperature of 50^0C?**

$$\alpha = 12 \times 10^{-6}\,{}^0C^{-1}$$
$$\Delta T = 40^0 C$$
$$L_0 = 25m$$

$$\Delta L = \alpha L_0 \Delta T = 1.20cm$$

5. **At 20^0C an aluminum ring and a brass rod have inside and outside diameters of 5.000cm and 5.050cm respectively.**

- To what temperature should the aluminum ring be heated to just slip over the brass rod?

We seek the value of *ΔT* for which *ΔL* will be 0.050cm.

$$0.050cm = (24 \times 10^{-6}\,{}^0C^{-1})(5.000cm)(\Delta T) \Rightarrow \Delta T = 416.6^0 C \therefore T = 436.6^0 C$$

- To what temperature must the combination then be heated to remove the aluminum ring from the brass rod?

$$\Delta L_{aluminum} = \Delta L_{brass} + 0.050cm \rightarrow \alpha\left(\Delta L_0\right)_{aluminum} \Delta T = \alpha\left(\Delta L_0\right)_{brass} \Delta T + 0.050cm$$

$$\Delta T = 2079^0 C \therefore T = 2099^0 C!$$

Clearly, this will not be achieved since both metals will melt in the process.

6. **What is the final equilibrium temperature when 10 grams of milk @ 10^0C is added to 160 grams of coffee @ 90^0C? Assume that the heat capacities of the liquids are both that of water. Assume a perfect calorimeter.**

$$-m_c c_c \Delta T = m_m c_m \Delta T$$

$$(160g)(1cal/g^0C)(90^0C - T_f) = (10g)(1cal/g^0C)(T_f - 10^0C)$$

$$\therefore T_f = 85.3^0C$$

7. **Copper pellets (m = 0.001kg) are heated to 100^0C. How many pellets must be added to 500g of water @ 20^0C to produce a final equilibrium temperature of 25^0C? Assume a perfect calorimeter.**

$$-m_c c_c \Delta T = m_w c_w \Delta T \Rightarrow m_c = 361g \therefore 361 pellets @ 1g / pellet$$

8. **A 1.5 kg iron horseshoe @ 600^0C is dropped into a bucket of water @ 25^0C. If the mass of water is 20 kg, what is the final temperature? Assume a perfect calorimeter.**

$$-m_i c_i \Delta T = m_w c_w \Delta T \Rightarrow T_f = 29.6^0C$$

9. **If 200g of water is contained in a 300g aluminum vessel @ 10^0C, and an additional 100g of water @ 100^0C is poured into the container, what is the final temperature of the system?**

$$-m_{hw} c_{hw} \Delta T = m_w c_w \Delta T + m_{al} c_{al} \Delta T \Rightarrow T_f = 34.7^0C$$

10. If 250g of ice @ 0^0C is added to 600g of water @ 18^0C in a perfect calorimeter, what is the final temperature of the system? How much ice remains?

What energy would be required to completely melt the ice?

$$Q = mL_f = (0.25kg)(3.33\times10^5\ J/kg) = 8.3\times10^4\ J = 19883cal$$

How much energy is required to cool 600g of water from 18^0C to 0^0C?

$$Q = mC\Delta T = (600g)(1cal/g^0C)(18^0C) = 10800cal$$

The system is 9083 calories short of enough energy to melt all of the ice. The final temperature of the system is 0^0C. How much ice remains?

$$\frac{Q}{L_f} = m \rightarrow \frac{45209J}{3.33\times10^5\ J/kg} = 0.136kg = 136g \text{ (converted to water)}$$

∴250g – 136g = 114g of ice remaining.

11. An aluminum calorimeter (*m* = 100g) contains 250g of water in equilibrium @ 10^0C. Two metal blocks are placed in the water. Block 1 is 50g of copper @ 80^0C; block 2 is 70g @ 1000C. The entire system comes to equilibrium @ 20^0C. Determine the specific heat of block 2 and identify its composition.

Equate heat lost by blocks 1 & 2 to heat gained by the calorimeter and water.

$$-(m_{B1}c_{B1}\Delta T + m_{B2}c_{B2}\Delta T) = m_w c_w \Delta T + m_{al}c_{al}\Delta T$$

$$m_{B1}c_{B1}(T_i - T_f) + m_{B2}c_{B2}(T_i - T_f) = (m_w c_w + m_{al}c_{al})(T_f - T_i)$$

$$(50g)(0.0924cal/g^0C)(60^0C) + (70g)(c_{B2})(80^0C) =$$
$$[(250g)(1cal/g^0C) + (100g)(0.215cal/g^0C)](10^0C)$$

∴c_{B2} = 0.435 cal/g^{0}C (beryllium)

12. A 3g lead bullet (@ 0^0C) is traveling at a speed of 240m/s when it comes to rest inside a very large block of ice @ 0^0C. What quantity of the ice melts?

$$\Delta KE = W_{nc} = \frac{1}{2}mv^2 = Q = mL_f \;\therefore \frac{1}{2}(0.003kg)(240\,m/s)^2 = (m_{ice})(3.33\times 10^5\; J/kg)$$

The mass of ice melted is 0.26g.

13. The volume of Lake Erie is roughly 4 × $10^{11}m^3$.

- How much heat would be required to raise the temperature of Lake Erie from 11^0C to 12^0C?

Recall that density = mass/volume.

$$m = (4\times 10^{11}\,m^3)(1000\,kg/m^3) = 4\times 10^{14}\,kg$$

$$Q = (4\times 10^{14}\,kg)(4186\,J/kg\,^0C)(1^0\,C) = 1.68\times 10^{18}\,J$$

- About how many years would it take to do this with a typical 1000MW power plant?

$$\frac{1.68\times 10^{18}\,J}{1\times 10^9\;J/s} = 1.68\times 10^9\,s$$

About 53 years.

14. A gas is compressed at a constant pressure of 0.8 atm from a volume of 9L to a volume of 2L. In the process 400 Joules of heat energy flows out of the gas.

- What is the work done by the gas?

In an isobaric process, *W = P∆V*.

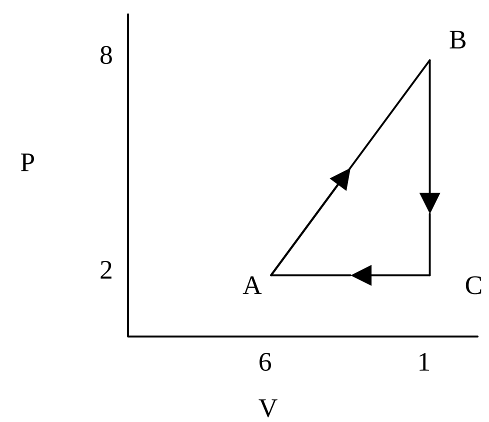
$$W = (0.8atm)(-7L)\left(\frac{1.013\times10^5\ N/m^2}{atm}\right)\left(\frac{m^3}{1000L}\right) = -567J$$

Work is done on the gas in compressing it.

- What is the change in internal energy of the gas?

$$\Delta U = Q - W = -400J - (-567J) = 167J$$

15. A gas is taken through the cyclic process shown in the figure below.



- Find the net heat transferred to the system in one complete cycle.

A cyclic process ∴∆U = 0 & Q = W.

W = area under the PV curve = $\left(\frac{1}{2}\right)(4m^3)(6kPa) = 12.0kJ$

- If the cycle is reversed, what is the net heat transferred during the cycle?

-12.0kJ

16. Five moles of an ideal gas expands isothermally at 127^{0}C to four times its initial volume.

- Find the work done by the gas

For an isothermal expansion, $\Delta U = 0$ & PV = constant.

$$V_2 = 4V_1 \to W = \int Pdv = \int_{V_i}^{V_f} \frac{nRT}{V} dv = nRT \ln \frac{V_f}{V_i}$$

$$= (5mol)(8.314\, J/K \cdot mol)(400K)\ln 4$$

= 23.1 kJ

- Find the heat flow into the system

$\Delta U = 0 \Rightarrow Q = W \therefore$ **23.1 kJ**

17. Two moles of helium (an ideal gas) initially @ 300K, 0.4 atm is compressed isothermally to a pressure of 1.2 atm.

- Find the initial and final volume of the gas.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = nRT$$

$$T_1 = T_2 \therefore P_1V_1 = P_2V_2 = nRT \therefore V_2 = \frac{P_1V_1}{P_2} = nRT$$

$\therefore$ $\boldsymbol{V_1 = 0.123m^3}$ **&** $\boldsymbol{V_2 = 4.11 \times 10^{-2}m^3}$

- What is the work done by the gas? Note: $\frac{V_f}{V_i} = \frac{0.0411}{0.123} \cong \frac{1}{3}$

$$W = \int PdV = nRT \ln \frac{1}{3} = -5.48kJ$$

- What is the heat transferred?

For an isothermal process $\Delta U = 0 \Rightarrow Q = W \therefore$ **Q = -5.48*kJ***

18. A 1 kg block of aluminum is heated at atmospheric pressure such that its temperature increases from 22^{0}C to 40^{0}C.

- Find the work done by the aluminum during expansion. Use the linear coefficient of expansion for solids and multiply by 3 for volume.

$$W = P\Delta V = \left[(1.013\times10^{5}\,Pa)\right]\left[(3)(24\times10^{-6}\,{}^{0}C^{-1})\left(\frac{1kg}{2.7\times10^{3}\,kg/m^{3}}\right)(18^{0}\,C)\right]$$

= **48.6 mJ**

- How much heat is added to the aluminum during this process?

$$Q = mc\Delta T = (1kg)(900\,J/kg^{0}C)(18^{0}C) = 16.2kJ$$

- What is the change in internal energy in the aluminum?

ΔU = Q – W = 16.2 kJ – 48.6 mJ = **16.2 kJ**

19. A Thermopane window 6m^2 in area is constructed from two layers of glass each 4mm thick separated by an air space of 5mm. The window has a temperature difference between the faces of 50^{0}C. What is the heat loss through the window?

$$\frac{\Delta Q}{\Delta T} = H = \frac{A(T_2 - T_1)}{\sum_i \frac{L_i}{k_i}} = \frac{6m^{3}(50^{0}C)}{(glass)\frac{(2)(4\times10^{-3}m)}{0.8W/m^{0}C} + (air)\frac{(5\times10^{-3}m)}{0.0234W/m^{0}C}} = 1.34kW$$

20. In each cycle of its operation a refrigerator absorbs 100 J from the cold reservoir and expels 130 J.

- What is the power required to operate this refrigerator if it works at 60 cycles?

$$W = Q_h - Q_c = 30J \Rightarrow (60\,cycles/s)(30J) = 1800\,J/s = 1.8kW$$

- What is the COP for the refrigerator?

$$COP_{refrigerator} = \frac{Q_c}{W} = 3.33J$$

21. A Carnot engine has a power output of 150 kW. The engine operates between two reservoirs at 20^{0}C and 500^{0}C.

- How much heat is absorbed per hour?

W = 150 kW, T_c = 293K, T_h = 773K

$$e = \frac{W}{Q_h} = 1 - \frac{T_c}{T_h} \therefore Q_h = \frac{\left(\frac{W}{t}\right)t}{1 - \left(\frac{T_c}{T_h}\right)} = \frac{(1.5\times10^5\,J/s)(3600s)}{1 - \frac{293K}{773K}} = 8.7\times10^8\,J$$

- How much heat energy is lost per hour?

$$Q_c = Q_h - \left(\frac{W}{t}\right)t = 3.3\times10^{18}\,J$$

22. Eco-terrorists bomb the last remaining fossil fuel power plant and replace it with a power plant that makes use of the temperature gradient in the ocean to produce energy. The system is designed to operate between 20^0C surface water and 5^0C water at a depth of about a kilometer.

- What is the maximum efficiency of such a system?

$$e = 1 - \frac{278K}{293K} = 5.12\%$$

- If the power output of the plant is 75 MW, how much thermal energy is absorbed per hour?

$$Q_h = \frac{W}{e} = \frac{\left(75 \times 10^6\ J/s\right)(3600s)}{0.0512} = 5.27 \times 10^{12}\ J$$

This is an impractical scheme since it would take a lot of ocean to supply five petajoules of energy!

What if one were to drill a hole through the earth's crust into the mantle the temperature gradient would be greater – 20^0 at the surface to about 100^0 at the upper boundary of the mantle. Would this make a better power plant? (~21% efficiency)

23. An ideal gas is taken through a Carnot cycle. The isothermal expansion occurs at 250^{0}C, and the isothermal compression takes place at 50^{0}C. If the gas absorbs 1200 J of heat during the isothermal expansion, find:

- The heat expelled to the cold reservoir during each cycle.

$$Q_c = Q_h \frac{T_c}{T_h} = 741J$$

- The net work done by the gas in each cycle.

$$W = Q_h - Q_c = 459J$$

24. What is the change in entropy when one mole of silver (108g) is melted at 961^{0}C?

$$\Delta S = \int \frac{dQ_r}{T} = \frac{1}{T_m}\int dQ = \frac{Q}{T_m} = \frac{mL_f}{T_m} = \frac{(0.108kg)(8.82\times10^4\ J/kg)}{1234K} = 7.72\ J/K$$

25. An avalanche of snow, mass = 1000kg, slides down a mountainside a vertical distance of 200 meters. What is the total change in entropy if the ambient temperature is –3^{0}C?

$$\Delta S = \frac{Q}{T} = \frac{mgh}{T} = 7260\ J/kg$$