General Physics II - Spring 2019

Homework Solutions to problems from Giancolli 7th Edition

Thermal Physics Problems

1 Fundamental Equations

Ideal gas:

$$PV = N\frac{2}{3}\bar{K}_{\text{trans}}$$

$$\bar{K}_{\text{trans}} = 3\frac{1}{2}kT$$

Each degree of freedom has on average $\frac{1}{2}kT$.

Heat Capacity:

$$C = \frac{dU}{dT}$$

Specific Heat:

$$c = \frac{C}{m}$$

Molar specific heat:

$$c = \frac{C}{n}$$

For a monotonic idea gas the total internal energy is

$$U = N3\tfrac{1}{2}kT \;\longrightarrow\; \frac{dU}{dT} = N3\tfrac{1}{2}k$$

so

$$c = \frac{C}{n} = \frac{dU/dT}{N/N_A} = \frac{N3\frac{1}{2}k}{N/N_A} = 3\tfrac{1}{2}kN_A = 3\tfrac{1}{2}R$$

Latent Heat:

$$Q = m\ell$$

Heat Conduction:

$$\frac{dQ}{dt} = kA\frac{dT}{dx}$$

Radiation:

$$\frac{dQ}{dt} = \sigma\epsilon AT^4$$

14.15 The change in the temperature of the glass is

$$\Delta T_g = T_{\text{final}} - T_{\text{initial}} = 41.8℃ - 23.6℃ = 18.2C^\circ$$

while the change in temperature of the water is

$$\Delta T_w = T_{\text{final}} - T_{\text{initial}} = 41.8℃ - T$$

where T is the unknown initial temperature of the water. The change in internal energy of the glass is

$$\Delta U_g = m_g c_g \Delta T_g$$

where c_g and m_g are the specific heat and mass of the glass. The change in internal energy of the water is

$$\Delta U_w = m_w c_w \Delta T_w$$

where c_w and m_w are the specific heat and mass of the water. Since the net change in energy is zero we know that

$$\begin{aligned}
0 &= \Delta U_g + \Delta U_w & (1)\\
\longrightarrow\ -\Delta U_w &= \Delta U_g & (2)\\
\longrightarrow\ -m_w c_w \Delta T_w &= m_g c_g \Delta T_g & (3)\\
\longrightarrow\ -\Delta T_w &= \frac{m_g c_g}{m_w c_w} \Delta T_g & (4)\\
\longrightarrow\ T - 41.8℃ &= \frac{m_g c_g}{m_w c_w} \Delta T_g & (5)\\
\longrightarrow\ T &= 41.8℃ + \frac{m_g c_g}{m_w c_w} \Delta T_g & (6)\\
\longrightarrow\ T &= 41.8℃ + \frac{(31.5)(840)}{(135)(4186)} 18.2C^\circ = 42.7℃ & (7)\\
& & (8)
\end{aligned}$$

That $\Delta U_g + \Delta U_w = 0$ is an approximation based on the assumption that the energy exchanged to the environment is negligible over the time period of the measurement. This seems reasonable if the measurement is quick, because the amount of energy moved by conduction and radiation is proportional to the time of the transfer, so a short time means there is a small amount of energy transferred by conduction and radiation.

14.25 First the silver must be warmed from 25℃ to the temperature at which it will melt 961℃. This requires an amount of energy

$$Q_{\mathrm{warm}} = mc\Delta T = (23.5\mathrm{kg})\left(230\frac{\mathrm{J}}{\mathrm{kg}\cdot C^{\circ}}\right)(961℃ - 25℃) \quad (9)$$

$$= (23.5\mathrm{kg})\left(0.23\frac{\mathrm{kJ}}{\mathrm{kg}\cdot C^{\circ}}\right)(961℃ - 25℃) \quad (10)$$

Once it is to this temperature then we must supply the latent heat in order to melt it.

$$Q_{\mathrm{melt}} = m\ell_f = (23.5\mathrm{kg})\left(88\frac{\mathrm{kJ}}{\mathrm{kg}}\right)$$

So the total energy required is

$$Q_{\mathrm{total}} = Q_{\mathrm{warm}} + Q_{\mathrm{melt}} = 7.13\mathrm{MJ}$$

14.46 The total power will be

$$P = \frac{dE}{dt} = \sigma\epsilon A T^4 = \sigma(1)4\pi R^2 T^4 = 3.2 \times 10^{26}\,\mathrm{W}$$

At the earth this power is spread over a sphere with a radius of the radius r of the earths orbit. Thus the power per area is

$$I = \frac{P}{A} = \frac{P}{4\pi r^2} = 1.1\frac{\mathrm{kW}}{\mathrm{m}^2}$$

14.59 We assume that energy is conserved so that

$$\Delta K + \Delta U = 0$$

thus

$$\tfrac{1}{2}m\Delta v^2 + mc\Delta T = 0$$

$$\begin{aligned}
\Delta T &= -\frac{\Delta v^2}{2c} \\
&= -\frac{v_f^2 - v_i^2}{2c} \\
&= \frac{v_i^2 - v_f^2}{2c} = 0.14C^\circ
\end{aligned}$$

14.60 The rate of conducted energy is

$$P = kA\frac{dT}{dx}$$

So the power per area is

$$I = \frac{P}{A} = k\frac{dT}{dx} = 0.80\frac{\mathrm{W}}{C^\circ \cdot \mathrm{m}}\frac{1.0C^\circ}{30\mathrm{m}} = 0.027\frac{\mathrm{W}}{\mathrm{m}^2}$$

This is very much less than the intensity of the sunlight 1000 W/m^2.
The total energy conducted in 1 hour is

$$\Delta E = IA\Delta t = I4\pi R^2\Delta t = I4\pi R^2(3600\mathrm{s}) = 4.9\times 10^{16}\mathrm{J}$$

The total solar energy absorbed in 1 hour is

$$\Delta E_{\mathrm{sun}} = I_{\mathrm{sunlight}}A\Delta t = I_{\mathrm{sunlight}}\pi R^2\Delta t = 4.6\times 10^{20}\mathrm{J}$$

We use the area of a circle here since from the earth only blocks this much sunlight. We used the surface area of a sphere for the power through conduction because the conduction happens all over the surface of the earth.