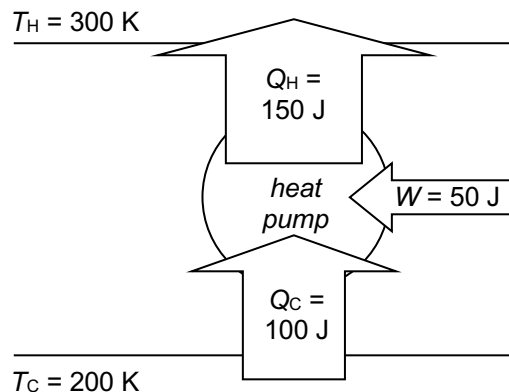


1. a) $\text{COP}_{\text{heat pump}} = \frac{Q_{\text{useful}}}{W} = \frac{Q_H}{W} = \frac{100 \text{ J}}{25 \text{ J}} = \underline{4.0}$
- b) $\text{COP}_{\text{heat pump}} = \frac{Q_H}{Q_H - Q_C} = \frac{100 \text{ J}}{100 \text{ J} - 75 \text{ J}} = \underline{4.0}$
- c) $\text{COP}_{\text{heat pump}} = \frac{T_H}{T_H - T_C} = \frac{300 \text{ K}}{300 \text{ K} - 225 \text{ K}} = \underline{4.0}$

2. a), b) and d)



b) $Q_C = Q_H - W = 150 \text{ J} - 50 \text{ J} = \underline{100 \text{ J}}$

c) $\text{COP}_{\text{heat pump}} = \frac{Q_{\text{useful}}}{W} = \frac{Q_H}{W} = \frac{150 \text{ J}}{50 \text{ J}} = \underline{3.0}$

d) $\text{COP}_{\text{heat pump}} = \frac{T_H}{T_H - T_C}$

$$\text{COP}_{\text{heat pump}} \cdot (T_H - T_C) = T_H$$

$$\text{COP}_{\text{heat pump}} \cdot T_H - \text{COP}_{\text{heat pump}} \cdot T_C = T_H$$

$$\text{COP}_{\text{heat pump}} \cdot T_H - T_H = \text{COP}_{\text{heat pump}} \cdot T_C$$

$$T_H (\text{COP}_{\text{heat pump}} - 1) = \text{COP}_{\text{heat pump}} \cdot T_C$$

$$T_C = \frac{T_H \cdot (\text{COP}_{\text{heat pump}} - 1)}{\text{COP}_{\text{heat pump}}} = \frac{300 \text{ K} \cdot (3.0 - 1)}{3.0} = \underline{200 \text{ K}}$$

3. Dividing by a small number gives a large result. Therefore the number below the fraction bar needs to be small, that is for $\text{COP}_{\text{heat pump}} = \frac{T_H}{T_H - T_C}$ the difference in temperature ($T_H - T_C$) ought to be small.

$$4. \quad a) \text{COP}_{\text{heat pump}} = \frac{T_H}{T_H - T_C} = \frac{293 \text{ K}}{293 \text{ K} - 263 \text{ K}} = \underline{9.77}$$

$$b) W = \frac{Q_H}{\text{COP}_{\text{heat pump}}} = \frac{6.00 \text{ J}}{9.77} = \underline{614 \text{ kJ}}$$

$$c) Q_C = Q_H - W = 6.00 \text{ MJ} - 0.614 \text{ MJ} = \underline{5.39 \text{ MJ}}$$

$$d) P = \frac{W}{t} = \frac{614 \text{ kJ}}{3600 \text{ s}} = \underline{170 \text{ W}}$$

$$5. \quad \text{COP}_{\text{heat pump}} = \frac{T_H}{T_H - T_C} \qquad \text{COP}_{\text{heat pump}} (T_H - T_C) = T_H$$

$$\text{COP}_{\text{heat pump}} \cdot T_H - \text{COP}_{\text{heat pump}} \cdot T_C = T_H$$

$$\text{COP}_{\text{heat pump}} \cdot T_H - T_H = \text{COP}_{\text{heat pump}} \cdot T_C \qquad T_H (\text{COP}_{\text{heat pump}} - 1) = \text{COP}_{\text{heat pump}} \cdot T_C$$

$$T_H = \frac{\text{COP}_{\text{heat pump}} \cdot T_C}{\text{COP}_{\text{heat pump}} - 1} = \frac{4.0 \cdot 288 \text{ K}}{4.0 - 1} = 384 \text{ K} = \underline{111 \text{ }^\circ\text{C}}$$

6. a) In order to cool a room, heat needs to flow from the **inside** of the room to the **outside** of the room. The heat is carried by a refrigerant, which **absorbs** heat on the inside and **releases** heat on the outside. Inside, you get the refrigerant to **vaporize**, and outside you get it to **condense**. Inside the room the pressure exerted on the refrigerant is **lowered** and outside it is **increased**. The increase in pressure is achieved using a **compressor**.

b) Because the heat needs to be released outside of the room which is to be cooled.

c) If you leave the windows open, warm air will flow into the cool room and heat it up.

$$7. \quad a) \text{COP}_{\text{refrigerator}} = \frac{T_C}{T_H - T_C} = \frac{275 \text{ K}}{298 \text{ K} - 275 \text{ K}} = \underline{12}$$

$$b) Q_{\text{water}} = \Delta U = c_{\text{water}} \cdot m_{\text{water}} \cdot \Delta T_{\text{water}} = 4182 \frac{\text{J}}{\text{kg}\cdot\text{K}} \cdot 5.00 \text{ kg} \cdot 58 \text{ K} = 1213 \text{ kJ} = \underline{1.2 \text{ MJ}}$$

c) The heat absorbed from the water is $Q_{\text{water}} = Q_{\text{useful}} = Q_C = 1.2 \text{ MJ}$

$$\text{COP}_{\text{refrigerator}} = \frac{Q_{\text{useful}}}{W} = \frac{Q_C}{W} \qquad W = \frac{Q_C}{\text{COP}_{\text{refrigerator}}} = \frac{1213 \text{ kJ}}{12} = \underline{101 \text{ kJ}}$$

$$d) Q_H = Q_C + W = 1213 \text{ kJ} + 101 \text{ kJ} = 1314 \text{ kJ} = \underline{1.3 \text{ MJ}}$$

e) First, let the water cool down to room temperature. Then put it into the fridge. In that case the water releases

$$Q_{\text{water}} = \Delta U = c_{\text{water}} \cdot m_{\text{water}} \cdot \Delta T_{\text{water}} = 4182 \frac{\text{J}}{\text{kg}\cdot\text{K}} \cdot 5.00 \text{ kg} \cdot 23 \text{ K} = 481 \text{ kJ}$$

The refrigerator absorbs the heat $Q_{\text{water}} = Q_{\text{useful}} = Q_C$ from the water and the work done is

$$W = \frac{Q_C}{\text{COP}_{\text{refrigerator}}} = \frac{481 \text{ kJ}}{12} = \underline{40 \text{ kJ}}$$

$$8. \quad \text{COP}_{\text{refrigerator}} = \frac{T_C}{T_H - T_C} = \frac{277 \text{ K}}{298 \text{ K} - 277 \text{ K}} = 13.2$$

$$Q_{\text{water}} = \Delta U = c_{\text{water}} \cdot m_{\text{water}} \cdot \Delta T_{\text{water}} = 4182 \frac{\text{J}}{\text{kg} \cdot \text{K}} \cdot 4.00 \text{ kg} \cdot 54 \text{ K} = 903.3 \text{ kJ}$$

The refrigerator absorbs the heat $Q_{\text{water}} = Q_{\text{useful}} = Q_C = 903.3 \text{ kJ}$ from the water and the work done is

$$W = \frac{Q_C}{\text{COP}_{\text{refrigerator}}} = \frac{903.3 \text{ kJ}}{13.2} = 68.5 \text{ kJ}$$

The heat released to the kitchen is $Q_H = Q_C + W = 903.3 \text{ kJ} + 68.5 \text{ kJ} = \underline{972 \text{ kJ}}$