

7) Container with 1.20 kg of water at 20.0°C (293K) is placed in a freezer kept at -20.0°C (253K). What is the minimum electrical energy required by the freezer to freeze the water & bring it to thermal equilibrium with the freezer interior?

1) Cool water from $+20.0^{\circ}\text{C}$ to 0°C $\Delta T = -20.0\text{K}$

$$\text{Heat removed } Q_1 = mc\Delta T = 1.20\text{ kg} \times 4.186 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \times (-20.0\text{K}) \\ = -100.46\text{ kJ}$$

2) Freeze water at 0.0°C to ice at 0.0°C

$$\text{Heat removed } Q_2 = -mL_f = -1.20\text{ kg} \times 333.7 \frac{\text{kJ}}{\text{kg}} \\ = -400.44\text{ kJ}$$

3) Cool ice at 0.0°C to ice at -20.0°C $\Delta T = -20.0\text{K}$

$$\text{Heat removed } Q_3 = mc\Delta T = 1.20\text{ kg} \times 2.1 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \times (-20.0\text{K}) \\ = -50.4\text{ kJ}$$

$$\text{Total heat removed} = -100.46\text{ kJ} - 400.44\text{ kJ} - 50.4\text{ kJ} = -551.3\text{ kJ}$$

$$W = Q \left(1 - \frac{T_H}{T_C}\right) = -551.3\text{ kJ} \left(1 - \frac{293}{253}\right) = (-551.3\text{ kJ}) \times (-0.158) \\ = 87.1\text{ kJ} \quad \text{(C)}$$