Heating & Cooling

Set 12: Specific Heat Capacity

12.1		No, since they have different specific heat capacities.
12.2	(a)	Convection losses from the surface of each cup should be the same, however heat would flow more quickly through the thinner more delicate china so this cup would cool down quicker.
	(b)	Brass has a higher specific heat capacity than pewter so the brass urn will take more heat away from the hot olive oil, meaning that the oil in the pewter urn will be hotter after 30 seconds.
12.3		$Q = m\,c\,\Delta T = 153\text{ kg} \times 4180\text{ J kg}^{-1}\text{ K}^{-1} \times (75\ ^\circ\text{C} - 15\ ^\circ\text{C}) = 38.4\text{ MJ}$
12.4		$Q = m\,c\,\Delta T = 0.782\text{ kg} \times 445\text{ J kg}^{-1}\text{ K}^{-1} \times (20\ ^\circ\text{C} - 445\ ^\circ\text{C}) = -148\text{ kJ}$
12.5		$\Delta T = \dfrac{Q}{mc} = \dfrac{1.548 \times 10^{6}\text{ J}}{72.6\text{ kg} \times 10^{3}\text{ J kg}^{-1}\text{ K}^{-1}} = 21.2\ ^\circ\text{C}$
12.6		electrical energy supplied = heat gained by kettle + heat gained by water 1 L of water has a mass of 1 kg $Q = m_{\text{kettle}} \times C_{\text{kettle}} \times \Delta T_{\text{kettle}} + m_{\text{water}} \times C_{\text{water}} \times \Delta T_{\text{water}}$ $Q = (0.355\text{ kg})(445\text{ J kg}^{-1}\text{ K}^{-1})(100\ ^\circ\text{C} - 15\ ^\circ\text{C}) + (0.850\text{ kg})(4180\text{ J kg}^{-1}\text{ K}^{-1})(100\ ^\circ\text{C} - 15\ ^\circ\text{C}) = 315\text{ kJ}$
12.7		$c = \dfrac{Q}{m\Delta T} = \dfrac{255.3 \times 10^{6}\text{ J}}{286\text{ kg} \times (452\ ^\circ\text{C} - 22\ ^\circ\text{C})} = 450\text{ J kg K}^{-1}$
12.8		$\Delta T = \dfrac{Q}{mc} = \dfrac{2.84 \times 10^{5}\text{ J}}{2.75\text{ kg} \times 4130\text{ J kg}^{-1}\text{ K}^{-1}} = 25.0\ ^\circ\text{C}$
12.9		$Q = m\,c\,\Delta T = 0.865\text{ kg} \times 900\text{ J kg}^{-1}\text{ K}^{-1} \times (120\ ^\circ\text{C} - 55\ ^\circ\text{C}) = 50.6\text{ kJ}$
12.10		$c_{av} = \dfrac{Q}{m\Delta T} = \dfrac{118 \times 10^{3}\text{ J}}{0.385\text{ kg} \times (98.6\ ^\circ\text{C} - 18\ ^\circ\text{C})} = 3800\text{ J kg K}^{-1}$
12.11		The crust has a lower heat capacity than the filling and hence has less heat energy to transfer to your mouth and therefore has less energy to raise the temperature of your mouth and burn you. A minor effect is that the liquid filling may be a better conductor of heat to your mouth.
12.12		Heat a measured mass, M of the alloy to a known temperature, T and put into a well insulated and measured mass, m of water at known temperature, t. The measured final temperature, T_f of the mixture can be related to the specific heat capacity of the alloy: Heat lost by alloy + heat gained by water = 0 $M\,c_{\text{alloy}}\,(T_f - T) + m\,c_{\text{water}}\,(T_f - t) = 0$ hence c_{alloy} can be calculated.
12.13	(a)	Time to heat is inversely proportional to specific heat capacity. Ethylene glycol has a lower specific heat capacity than water and will reach 100 °C faster by a factor of:

		$\frac{c_{\text{water}}}{c_{\text{glycol}}} = \frac{4180\ \text{J kg}^{-1}\ \text{K}^{-1}}{2400\ \text{J kg}^{-1}\ \text{K}^{-1}} = 1.74$ So, it takes 1.74 times longer to heat the water.
	(b)	Water has a significantly higher specific heat capacity than ethylene glycol. Other factors, such as boiling point and corrosive effects, are also important. In terms of its ability to absorb heat energy without a large rise in temperature water is more efficient. However, even under pressure water will boil at about 120 °C. If the designer wants to run an engine at higher temperature (which is potentially more efficient) then a higher boiling point liquid is needed. Ethylene glycol boils at 198 °C and also is less corrosive to the metal parts than water. Often a mixture of the two is used.
	(c)	If a bigger mass of coolant was used, or if it were pumped through the system more rapidly, cooling could be improved.
12.14		The storage system must be fully enclosed and very well lagged to prevent heat escaping through its walls, its upper and lower surfaces. It should have a low coefficient of expansion so there is very little increase in size and less chance of fracturing. It should have a high melting point. Its inner walls should be silvery or shiny to prevent heat escaping by radiation.
12.15		$m = \frac{Q}{c\Delta T} = \frac{2.93 \times 10^{6}\ \text{J}}{4180\ \text{J kg K}^{-1} \times (100\ ^{\circ}\text{C} - 20\ ^{\circ}\text{C})} = 8.76\ \text{kg}$ (or just a little more than this in order to **prevent** the coolant water from boiling).
12.16		Energy required by water, $Q = m\,c\,\Delta T = 245\ \text{kg} \times 4180\ \text{J kg}^{-1}\ \text{K}^{-1} \times (68\ ^{\circ}\text{C} - 12\ ^{\circ}\text{C}) = 57.35\ \text{MJ}$ At 62% efficiency, the oil would therefore have to supply $\frac{57.35 \times 10^{6}\ \text{J}}{0.62} = 92.5\ \text{MJ}$ So mass of oil required, $m = \frac{Q}{Q_{\text{per kg}}} = \frac{92.5 \times 10^{6}\ \text{J}}{4.15 \times 10^{7}\ \text{J kg}^{-1}} = 2.23\ \text{kg}$
12.17		The longer the water remains in the bath tub, the more heat it will transfer to the colder air in the room as it attempts to reach the same ambient temperature and achieve thermal equilibrium. So it would effectively warm up the room.
12.18		Water has a much higher specific heat capacity than land. Hence the same heat input from the sun will raise the temperature of the land by much more than that for an equivalent amount of water.
12.19		microwave energy supplied = heat gained by glass + heat gained by water, $Q = (m_{\text{glass}}\, c_{\text{glass}}\, \Delta T_{\text{glass}}) + (m_{\text{water}}\, c_{\text{water}}\, \Delta T_{\text{water}})$ $Q = (0.215\ \text{kg})(670\ \text{J kg}^{-1}\ \text{K}^{-1})(98.5\ ^{\circ}\text{C} - 18.5\ ^{\circ}\text{C}) + (0.145\ \text{kg})(4180\ \text{J kg}^{-1}\ \text{K}^{-1})(98.5\ ^{\circ}\text{C} - 18.5\ ^{\circ}\text{C}) = 60\ \text{kJ}$
12.20		final temperature of soup, T_f = final temperature of the bowl = 97 °C Heat lost by soup + heat gained by bowl = 0 $m_{\text{soup}}\, c_{\text{soup}}\, (T_f - T)_{\text{soup}} + m_{\text{bowl}}\, c_{\text{bowl}}\, (T_f - t)_{\text{bowl}} = 0$ $(0.800\ \text{kg})(c_{\text{soup}})(97\ ^{\circ}\text{C} - 98\ ^{\circ}\text{C}) + (0.100\ \text{kg})(320\ \text{J kg}^{-1}\ \text{K}^{-1})(97\ ^{\circ}\text{C} - 10\ ^{\circ}\text{C}) = 0$ $c_{\text{soup}} = 3480\ \text{J kg}^{-1}\ \text{K}^{-1}$

12.21		Heat lost by tea + heat gained by water = 0 $m_{tea}\,c_{tea}\,(T_f - T)_{tea} + m_{water}\,c_{water}\,(T_f - t)_{water} = 0$ $(0.185\text{ kg})(4180\text{ J kg}^{-1}\text{ K}^{-1})(T_f - 85.5\,^{\circ}\text{C}) + (0.035\text{ kg})(4180\text{ J kg}^{-1}\text{ K}^{-1})(T_f - 18\,^{\circ}\text{C}) = 0$ gives $T_f = 74.8\,^{\circ}\text{C}$
12.22		1 L water has mass 1 kg Each hour, mass of water flowing, $m = 1300\text{ kg min}^{-1} \times 60\text{ min h}^{-1} = 78\,000\text{ kg h}^{-1}$ Each hour, energy transferred to water by the pump $= 10\,000\text{ J s}^{-1} \times 3600\text{ s h}^{-1} = 3.6 \times 10^{7}\text{ J h}^{-1}$ 35% of this energy is transferred as heat, $Q = 0.35 \times 3.6 \times 10^{7}\text{ J h}^{-1} = 1.26 \times 10^{7}\text{ J h}^{-1}$ So, during the hour, $\Delta T = \frac{Q}{mc} = \frac{1.26 \times 10^{7}\text{ J h}^{-1}}{78\,000\text{ kg h}^{-1} \times 4180\text{ J kg}^{-1}\text{ K}^{-1}} = 0.039\,^{\circ}\text{C}$
12.23		$\text{electrical energy input} = \frac{\text{heat gained by kettle} + \text{heat gained by water}}{0.65}$ since it is 65% efficient $Q = \frac{(m_{kettle}\,c_{kettle}\,\Delta T_{kettle}) + (m_{water}\,c_{water}\,\Delta T_{water})}{0.65}$ $Q = \frac{(5.25\text{ kg})(445\text{ J kg}^{-1}\text{ K}^{-1})(96\,^{\circ}\text{C} - 12\,^{\circ}\text{C}) + (1.55\text{ kg})(4180\text{ J kg}^{-1}\text{ K}^{-1})(96\,^{\circ}\text{C} - 12\,^{\circ}\text{C})}{0.65}$ $= 1.14 \times 10^{6}$ J (or 1.14 MJ)
12.24		85 % of the heat lost by hot water + heat gained by cold water = 0 (since bath & surroundings absorb 15%) $0.85\,(m_{hot})(c_{hot})(T_f - T)_{tea} + m_{cold}\,c_{cold}\,(T_f - t)_{cold} = 0$ $(0.85)(m_{hot})(4180\text{ J kg}^{-1}\text{ K}^{-1})(75.3\,^{\circ}\text{C} - 45\,^{\circ}\text{C}) + (40\text{ kg})(4180\text{ J kg}^{-1}\text{ K}^{-1})(45\,^{\circ}\text{C} - 16.5\,^{\circ}\text{C}) = 0$ gives $m_{hot} = 44.3$ kg
12.25		heat gained by glycol + (heat lost by radiator + heat lost by water) = 0 $(m_{glycol})(c_{glycol})(\Delta T_{glycol}) + (m_{radiator})(c_{radiator})(\Delta T_{radiator}) + (m_{water})(c_{water})(\Delta T_{water}) = 0$ $(0.655\text{ kg})(2400\text{ J kg}^{-1}\text{ K}^{-1})(T_f - 22\,^{\circ}\text{C}) + (4.5\text{ kg})(390\text{ J kg}^{-1}\text{ K}^{-1})(T_f - 92\,^{\circ}\text{C}) + (6.75\text{ kg})(4180\text{ J kg}^{-1}\text{ K}^{-1})(T_f - 92\,^{\circ}\text{C}) = 0$ gives $T_f = 88.5\,^{\circ}\text{C}$