Specific heat

Select LEARNING OBJECTIVES:

- Introduce specific heat in terms of thermal energy and apply the 1st law of thermodynamics to simplify specific heat into the more familiar term explicit in terms of heat.
- Be able to use specific heats of systems to determine how much energy it takes to raise the temperature of that system.

TEXTBOOK CHAPTERS:

- Giancoli (Physics Principles with Applications 7th) :: 14-3
- Knight (College Physics : A strategic approach 3rd) :: 12.5
- BoxSand :: [Heat]

WARM UP: What would an example of a system be that has both work and heat present? Is the thermal energy of your system increasing, decreasing, staying the same?

RUB HANDS TOGETHER NEXT TO A FIRE ...... COMPRESS A GAS IN A CYLINDER THAT IS PLACED IN AN ICE BATH.

$W^{F}\ (+)$ $\quad Q\ (+)$ $\qquad W^{PUSH}\ (+)$ $\quad Q\ (-)$

We talked about how to quantify a change in thermal energy of an ideal gas ($\Delta E^{th} = 3/2\ N\ k_B\ \Delta T$), but what if the object of interest was a solid or liquid? We would like to formulate a similar way in which we can determine how much the temperature will change if a given amount of energy is added or taken away from a solid or liquid. It turns out we can quantify this relationship for materials by a value known as the specific heat (c). The specific heat is then a measure of how much energy is required to change the temperature of a given mass of a substance. For example, the specific heat of aluminum is 900 J/(kg K), which is interperated as: it takes 900 joules of energy to raise the temperature of 1 kg woth of aluminum by 1 K unit. Mathematically the specific heat is written as…

$$\boxed{C = \frac{1}{m}\frac{\Delta E^{TH}}{\Delta T}}$$

Now that it's mathematically visible, the question might arise, why are we calling it specific "heat" when heat (Q) is not explicitly present? It turns out this is just poor terminology, you can really think of it as "specific energy". However for most of the processes we study, the way we will change our thermal energy will be via heat and not work. Recall that $\Delta E^{th} = Q + W_{ext}$. If $W_{ext} = 0$ then $\Delta E^{th} = Q$. And the specific heat can then be explicitely written in terms of heat.

$$C = \frac{1}{m}\frac{\Delta E^{TH}}{\Delta T} \sim \left.\begin{matrix}\text{IF } W=0 \\ E^{TH} = \cancel{W}^{0} + Q\end{matrix}\right\} \text{THEN } \Delta E^{TH} = Q \Rightarrow \boxed{C = \frac{1}{m}\frac{Q}{\Delta T}} \text{ OR } Q = mc\Delta T$$

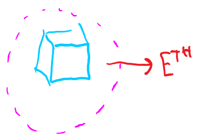
Specific heat is a material property, (i.e. the value of c is different for different types of materials). This means that samples of different materials all with the same mass will have different changes in temperature when introduced with the same amount of thermal energy. The specific heat is of a broader class of what we call response functions, which typically characterize how a macroscopic property of a system responds to a change in another quantity within the system. Here, the specific heat tells us how a substance's temperature will change if we change its thermal energy.

In general, the specific heat for any substance is a function of temperature. However, it is roughly constant over a limited range of temperatures, thus we will assume that the temperatures we work with in all of our problems fall within this range of roughly constant specific heat.

It should also be noted that we can define specific heats for gases. However, the specific heats for gases are generally a bit more complicated than the specific heats for solids and liquids. Recall from our discussion about the microscopic model of matter, we saw that gases are easily compressed while liquids and solids are not. Since the volume of a gas changes significantly with temperature the specific heat will likely no longer be in a region with a roughly constant value. Likewise, the pressure of a gas changes significantly with temperature, so if the pressures of a gas changes then the specific heat will again likely not be in a region with a roughly constant value. Basically, the specific heat of gases depends on how the process of changing the temperature is performed. You will likely encounter the most common specific heats of gasses, c_v and c_p; where c_v is the specific heat at a constant volume and c_p is the specific heat at a constant pressure. For this class, we will only deal with specific heats of solids and liquids.

PRACTICE: How much thermal energy must be removed from a 200 g block if ice to cool it from 0 °C to -30 °C. The specific heat of ice is 2090 J/(kg K).

(a) 10,500 J
(b) 11,500 J
[✓ (c)] 12,500 J
(d) 13,500 J
(e) 14,500 J



$$C_{ICE} = \frac{1}{M_{ICE}} \frac{\Delta E^{TH}}{\Delta T}$$

$$\Delta T(°C) = \Delta T(K)$$

$$\Delta E^{TH} = M_{ICE} C_{ICE} \Delta T$$

$$\Delta E^{TH} = (0.2\,kg)\left(2090 \frac{J}{kg\,K}\right)(-30\,K) \approx \boxed{-12{,}500\ J}$$

E^{TH} WAS REMOVED FROM SYSTEM

PRACTICE: 100 g of each of the following materials is heated. Each material gets the same amount of heat. Which material will increase in temperature the most?

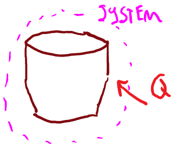
Copper: density = 8.96 g/cc ; melting point 1085 °C ; c = 385 J/kg°C ; conductivity = 401 W/m°C
Magnesium: density = 1.74 g/cc ; melting point 650 °C ; c = 1020 J/kg°C ; conductivity = 156 W/m°C
Aluminum: density = 2.70 g/cc ; melting point 660 °C ; c = 897 J/kg°C ; conductivity = 237 W/m°C

$$c = \frac{1}{m}\frac{Q}{\Delta T} \quad \text{w/ } \left.\begin{matrix} Q = \text{constant} \\ + m = \text{constant} \end{matrix}\right\} c \propto \frac{1}{\Delta T} \text{ OR } \Delta T \propto \frac{1}{c}$$

$$\therefore \boxed{\Delta T_{Cu} > \Delta T_{Al} > \Delta T_{Mg}}$$

PRACTICE: How much heat is need to raise the temperature of…

(a) …a 20 kg empty iron vat from 10 °C to 90 °C? (specific heat of iron is 449 J/kg K)



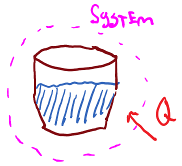
$$Q_{SYSTEM} = Q_{Fe} = M_{Fe} C_{Fe} \Delta T_{Fe}$$

$$\Delta T = 90°C - 10°C = 80°C \Rightarrow 80\,K$$

$$Q_{Fe} = (20\,kg)\left(449 \frac{J}{kg\,K}\right)(80\,K)$$

$$\boxed{Q_{Fe} \simeq 718000\ J} \text{ or } 7.18 \times 10^5\,J \text{ or } 7.18 \times 10^2\,kJ$$

(b) What if the vat was filled with 20 kg of water? (specific heat of water is 4190 J/kg K)



$$Q_{System} = Q_{Fe} + Q_W$$

$$= M_{Fe} C_{Fe} \Delta T_{Fe} + M_w C_w \Delta T_w$$

$$= 718400\,J + (20\,kg)\left(4190 \frac{J}{kg\,K}\right)(80\,K)$$

$$\boxed{Q_{System} \approx 7420000\ J}$$

OR

$$7.42 \times 10^6\,J$$

QUESTIONS FOR DISCUSSION:

(1) The term "specific heat capacity" suggests that an object can possess heat. Can a system possess heat? Based on your answer, would you change anything about that term "specific heat capacity"?

(2) The specific heat of an object depends on which of the following
    a. The amount of energy added or taken away from the object.
    b. The mass of the object.
    c. The density of the object.
    d. The material of the object.