15.2: Heat Capacities

When we supply heat energy from a bunsen burner or an electrical heating coil to an object, a rise in temperature usually occurs. Provided that no chemical changes or phase changes take place, the rise in temperature is proportional to the quantity of heat energy supplied. If q is the quantity of heat supplied and the temperature rises from T_1 to T_2 then

$$q = C * (T_2 - T_1)$$

OR

$$q = C * (\Delta T)$$

where the constant of proportionality C is called the **heat capacity** of the sample. The sign of q in this case is + because the sample has absorbed heat (the change was endothermic), and (ΔT) is defined in the conventional way.

If we add heat to any homogenous sample of matter of variable mass, such as a pure substance or a solution, the quantity of heat needed to raise its temperature is proportional to the mass as well as to the rise in temperature. That is,

$$q = C * m * (T_2 - T_1)$$

OR

$$q = C * m * (\Delta T)$$

The new proportionality constant C is the heat capacity per unit mass. It is called the **specific heat capacity** (or sometimes the specific heat), where the word *specific* means "per unit mass."

Specific heat capacities provide a convenient way of determining the heat added to, or removed from, material by measuring its mass and temperature change. As mentioned [|previously], James Joule established the connection between heat ***energy*** and the *intensive property* ***temperature***, by measuring the temperature change in water caused by the energy released by a falling mass. In an ideal experiment, a 1.00 kg mass falling 10.0 m would release 98.0 J of energy. If the mass drove a propeller immersed in 0.100 liter (100 g) of water in an insulated container, its temperature would rise by 0.234°C. This allows us to calculate the specific heat capacity of water:

98 J = C × *100 g* × 0.234 °C
C = 4.184 J/g°C

At 15°C, the precise value for the specific heat of water is 4.184 J K^{-1} g^{-1}, and at other temperatures it varies from 4.178 to 4.219 J K^{-1} g^{-1}. Note that the specific heat has units of g (not the base unit kg), and that since the Centigrade and kelvin scales have identical graduations, either °C or K may be used.

✔ Example 15.2.1: Specific Heat of Water

How much heat is required to raise the temperature of 500 mL of water (D = 1.0) from 25.0 °C to 75.0 °C, given that the specific heat capacity of water is 4.184 J K^{-1} g^{-1}?

Solution:

q = 4.18 J/g°C × 500 g × (75.0 - 25.0)
q = 104 500 J or 104 kJ.

Table 15.2.1 Specific heat capacities (25 °C unless otherwise noted)

Substance	phase	C_p*(see below)* J/(g·K)
air, (Sea level, dry, 0 °C)	gas	1.0035
argon	gas	0.5203

carbon dioxide	gas	0.839
helium	gas	5.19
hydrogen	gas	14.30
methane	gas	2.191
neon	gas	1.0301
oxygen	gas	0.918
water at 100 °C (steam)	gas	2.080
water at T=[1]	liquid	0.01°C 4.210 15°C 4.184 25°C 4.181 35°C 4.178 45°C 4.181 55°C 4.183 65°C 4.188 75°C 4.194 85°C 4.283 100°C 4.219
water (ice) at T= [2]	solid	0°C 2.050 -10°C 2.0 -20°C 1.943 -40°C 1.818
ethanol	liquid	2.44
copper	solid	0.385
gold	solid	0.129
iron	solid	0.450
lead	solid	0.127

Electrical Energy Conversion

The most convenient way to supply a known quantity of heat energy to a sample is to use an electrical coil. The heat supplied is the product of the applied potential *V*, the current *I* flowing through the coil, and the time *t* during which the current flows:

$$q = V * I * t$$

If the SI units volt for applied potential, ampere for current, and second time are used, the energy is obtained in joules. This is because the volt is defined as one joule per ampere per second:

$$1 \text{ volt} \times 1 \text{ ampere} \times 1 \text{ second} = 1 \frac{\text{J}}{\text{A s}} \times 1 \text{ A} \times 1 \text{ s} = 1 \text{ J}$$

Example $15.2.2$: Heat Capacity

An electrical heating coil, 230 cm^3 of water, and a thermometer are all placed in a polystyrene coffee cup. A potential difference of 6.23 V is applied to the coil, producing a current of 0.482 A which is allowed to pass for 483 s. If the temperature rises by 1.53 K, find the heat capacity of the contents of the coffee cup. Assume that the polystyrene cup is such a good insulator that no heat energy is lost from it.

Solution The heat energy supplied by the heating coil is given by

$$q = V * I * t = 6.23\text{V} * 0.482\text{A} * 483\text{s} = 1450\text{V A s} = 1450\text{J}$$

However,

$q = C * (T_2 - T_1)$

Since the temperatue rises, $T_2 > T_1$ and the temperature change ΔT is positive:

1450 J = C × 1.53 K

so that

$$C = \frac{1450 \text{ J}}{1.53 \text{ K}} = 948 \text{ J K}^{-1} \tag{15.2.1}$$

Note

Note: The heat capacity found applies to the complete contents of the cup-water, coil, and thermometer taken together, not just the water.

As discussed in other sections, an older, non-SI energy unit, the calorie, was defined as the heat energy required to raise the temperature of 1 g H_2O from 14.5 to 15.5°C. Thus at 15°C the specific heat capacity of water is 1.00 cal K^{-1} g^{-1}. This value is accurate to three significant figures between about 4 and 90°C.

If the sample of matter we are heating is a pure substance, then the quantity of heat needed to raise its temperature is proportional to the amount of substance. The heat capacity per unit amount of substance is called the molar heat capacity, symbol C_m. Thus the quantity of heat needed to raise the temperature of an amount of substance n from T_1 to T_2 is given by

$$q = C * n * (T_2 - T_1) \tag{15.2.2}$$

The molar heat capacity is usually given a subscript to indicate whether the substance has been heated at constant pressure (C_p)or in a closed container at constant volume (C_V).

Example 15.2.3: Molar Heat Capacity

A sample of neon gas (0.854 mol) is heated in a closed container by means of an electrical heating coil. A potential of 5.26 V was applied to the coil causing a current of 0.336 A to pass for 30.0 s. The temperature of the gas was found to rise by 4.98 K. Find the molar heat capacity of the neon gas, assuming no heat losses.

Solution The heat supplied by the heating coil is given by

$$q = V * I * t$$

$$\begin{aligned} &= 5.26\text{V} * 0.336\text{A} * 30.0\text{s} \\ &= 53.0\text{V A s} \\ &= 53.0\text{J} \end{aligned}$$

Rearranging Eq. 15.2.2, we then have

$$C_m = \frac{q}{n(\text{T}_2 - \text{T}_1)} = \frac{53.0 \text{ J}}{0.854 \text{ mol} \times 4.98 \text{ K}} = 12.47 \text{ J K}^{-1} \text{ mol}^{-1} \tag{15.2.3}$$

However, since the process occurs at constant volume, we should write

C_V = 12.47J K^{-1} mol^{-1}

References

1. http://www.engineeringtoolbox.com/water-thermal-properties-d_162.html
2. http://www.engineeringtoolbox.com/ice-thermal-properties-d_576.html

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15.2.1: Lecture Demonstrations

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