Heat Capacity and calorimetry

Imagine it's a hot summer day, and you need to go get some groceries. You get up, get dressed, and get in your car. Just as you do though, you burn your hand on the door handle! As you get into the car, you wonder why only the door handle burns.

This demonstrates today's lesson: heat capacity. Different substances require a different amount of energy to increase their temperature. This is true across the periodic table, and this phenomenon can be mathematically modelled.

Overview

- In this lesson, you'll learn what **heat capacity** and **specific heat** is
- Then, you'll learn how to calculate it with a **general formula**
- Afterwards, we'll cover the general heat capacity of **metals** and **water**
- Lastly, we'll walk through how to solve common AP-styled **heat capacity problems**

Heat Capacity Definition

Now, let's imagine that on this hot summer day, we decided to go swimming. Just using your intuition, which do you think would warm up faster: a glass of water we're drinking outside, or the swimming pool itself. Naturally, a glass of water is going to heat up much quicker than an entire pool. But why is this the case? It has to do with differing heat capacities.

> Definition
>
> **Heat capacity** is defined as the amount of energy needed to increase a substance's temperature by 1°C. It's influenced by both the actual chemical substance, and the mass of the object it forms.

In this case, the glass and pool both have effectively the same chemical composition: water. However, because of the difference in mass, the glass of water heats up much faster. This general trend is consistent for other substances as well! If the chemical composition is equivalent for two objects, determining the relative heat capacity falls to the variable of mass. Likewise, the inverse is true. However, when analyzing two objects for differing heat capacities, it is usually wise to start with the chemical composition.

In theory, this makes sense. But it would be quite tedious to recalculate the heat capacity for different objects that have the same chemical composition. To resolve this, chemists devised the concept of specific heat.

> Definition
>
> A substance's **specific heat** is the amount of energy it takes to increase its temperature by 1°C per gram.

Turning back to our comparison between the glass of water and the swimming pool, these objects have different heat capacities. However, they both are made of water, which has a constant specific heat. We can think about this concept from another perspective. We know that heat capacity is influenced by mass and chemical composition- but specific heat describes the influence that chemical composition brings.

Therefore, we can think of heat capacity as defined as a factor (from mass) of specific heat. In other words: water has the same specific heat, but as we increase the amount of water, it takes more time to reach the specific heat for the entire container of water. To convey this connection between heat capacity and specific heat, the formula used to derive an object's heat capacity is called the **specific heat capacity.**

If this seems a bit too abstract to visualize, perhaps looking at this concept mathematically will make more sense.

Specific Heat Capacity Formula

To solidify your understanding of heat capacity being influenced by both mass and chemical composition, let's take a look at how to calculate it. The general formula for specific heat capacity is as follows:

$$Q = mc\,\Delta T$$

Where Q is the amount of energy required to increase an object of mass *m* and heat capacity *c* a certain amount of °C (represented by *delta T*.) It's important to make clear that the *specific* heat capacity c is the specific heat of the chemical substance of our object in question. If we were to apply this to our pool example, we'd use *m* to represent the pool water's mass, and *c* would represent water's specific heat capacity.

A fun way to remember this equation is "q = m cat." Obviously, there is no variable under the letter a- the delta symbol just looks like a capital A. However, it should be enough to remember the formula.

Deep dive

Remember that heat capacity is influenced by both mass and chemical composition. Specific heat is ONLY influenced by chemical composition. This is why the specific heat capacity formula above includes m as a multiplying factor. If we wanted to calculate the amount of energy to do this same change with heat capacity instead of specific heat, we could do that:

$$Q = C\,\Delta T$$

Where capital C represents the heat capacity of the object, which represents chemical composition and mass. This is why the mass variable is not present.

What happens when we apply this specific heat capacity formula to common substances such as water or metals?

Heat Capacity of Water and Metals

If you recall the example we gave at the beginning of this lesson, our metal door handle became hot to the touch much more quickly than other parts of the car. We've also talked about how this phenomenon is modelled theoretically and mathematically. If we applied this model to common substances that you may encounter in AP problems, what specific heat capacities would we get? *Note: you most likely won't have to memorize these, but it would be good to recall the specific heat capacities for water.*

Chemical Substance	Specific Heat (J/g°C)
Water $_{(l)}$	4.18
Water $_{(s)}$	2.06
Water $_{(g)}$	1.87
Ammonia $_{(g)}$	2.09
Carbon $_{(s)}$	0.71
Iron $_{(s)}$	0.45
Copper $_{(s)}$	0.39
Silver $_{(s)}$	0.23

Again, you won't have to memorize these for the AP exam.

Heat Capacity and Calorimetry in the AP Exam

Now that we've reviewed heat capacity, specific heat, and how to calculate the specific heat capacity, how would this information appear in the AP Chemistry exam? Let's try a few practice problems to ensure you understand the concept.

Let's start by trying to solve for q first.

> **Example**
>
> How much energy does it take to heat 3 kg of water from 10 C to 40 C? Answer in kJ.
>
> $$q = mc\Delta T$$
> $$q = (3000\,g)(4.18)(40-10)$$
> $$q = 376200\ J = 376.2\ kJ$$

> Recall that our units for mass are always in grams. This means we need to convert kg to g. Problems may ask for you to convert your final answer into a different unit, such as J to kJ), so be sure to read the problem carefully.

Now, let's try to solve for c.

> **Example**
>
> A 25 g sample of a metal with an unknown identity is heated at 35.6°C with 400 J of energy. What element is the unknown metal?
>
> $q = mc\Delta T$
> $400\ J = (25\ g)c(35.6)$
> $c = 0.45$
>
> Comparing our calculated c value to our specific heat table in the previous section, we can tell the mystery metal here is iron.

Lastly, let's try a more abstract problem.

> **Example**
>
> If we have 0.47 kg of ammonia gas resting at 5°C, how hot can we make it with 2.4 kJ of energy?
>
> $q = mc\Delta T$
> $2400 = (470\ g)(2.09)(T_f - 5)$
> $T_f = 7.44°C$
>
> Remember to keep your units consistent! In an actual AP problem, you would be provided with the c constant. In this example, we're able to increase our sample of ammonia gas from 5°C to 7.44°C.

Hopefully, seeing these examples help you to grasp the flexibility of the specific heat capacity formula and how it may appear in the AP Chemistry exam. Be sure to read heat capacity problems carefully, as units and what answer is specifically asked for are often subject to change.

Heat Capacity and calorimetry - Key takeaways

- In this lesson, we covered what heat capacity and specific heat is
- Afterwards, we taught you how to calculate it with the specific heat capacity formula
- Next, we went over the general heat capacity of certain common metals and water
- Lastly, we stepped through some AP-styled heat capacity problems