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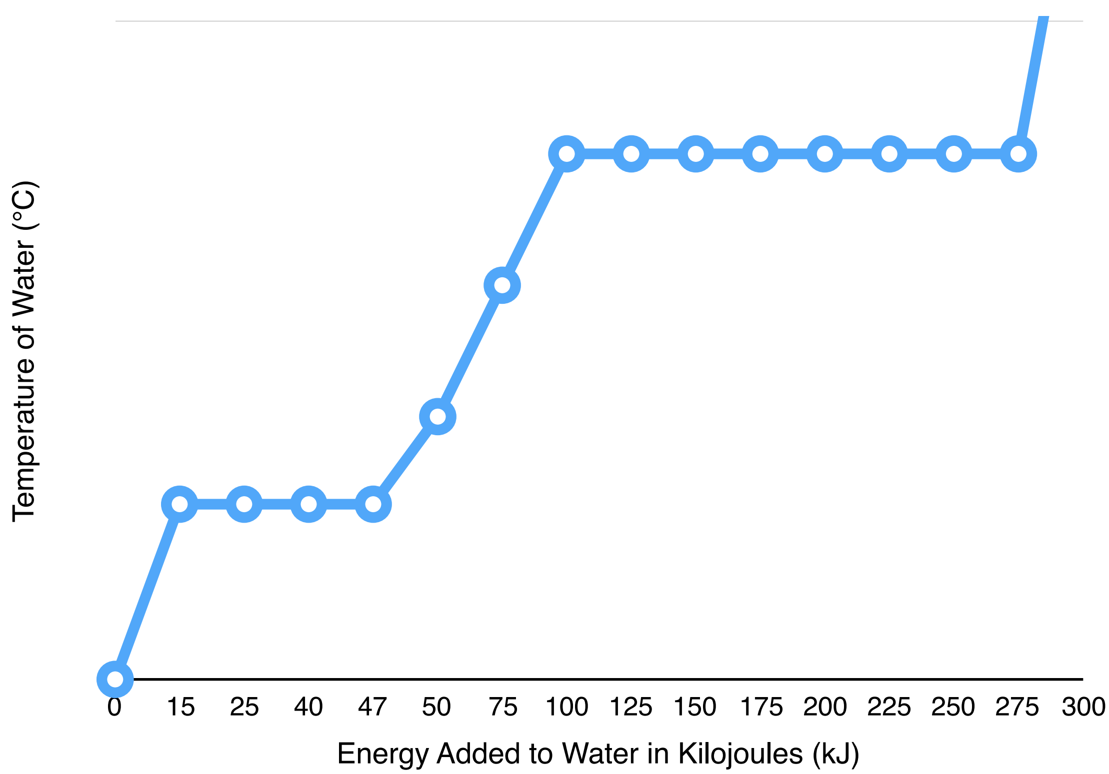
# Changing States of Matter

## Energy Required to Change State

As you've figured out, it takes quite a lot of energy to heat a substance such as water. **Significant amounts of energy are also required to get materials to change state (changing from a solid to liquid, or liquid to gas).**

Water does not automatically boil once it reaches 100°C. If it did, when you boiled water in a pan, it would all suddenly disappear once the water reached 100°C. When water reaches 100°C, you have to keep adding energy to boil it all (vaporize it). That extra energy you're adding allows the molecules to separate from one another. The temperature of the steam you are creating will only rise after all of the water has been turned to steam. In other words, after the **phase change**, if more energy is applied, the temperature will go up.

You understand this from putting ice in a glass of water - the water will not begin to heat up until all of the ice has melted into the water. The water doesn't become warm around the ice while there is still ice in the cup.



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1. What do the horizontal parts of the graph represent? What is happening during that part of the graph? (If you are unsure, read the section titled “Energy Required to Change State” again)

2. Calculate the values for and label the temperature scale on the graph. Think about where energy is being added but temperature is not increasing. Label what state the water is in between each horizontal section as well.

3. Which requires more energy: vaporizing water into steam, or melting ice into water? Explain. *Hint: The graph is helpful here.*

### Mathematics of Changes of State

If we rearrange our specific heat equation to solve for energy, it looks like this:
$\mathbf{q = (m)(C_p)(\Delta T)}$

This equation only works when the substance you are heating is **not changing state** (undergoing a **phase change**).

If the state does change, you need to add an extra step to your equations. This introduces a new term: **enthalpy,** or the energy required for a change of state. So the “enthalpy of vaporization” (symbolized by $\Delta H_{vap}$) of water is the energy needed to vaporize (or boil) one gram of water when the water is <u>already at its boiling point</u>. The **$\Delta H_{vap}$ of water is 2260 J/g**. So for each gram of hot (100°C) water, 2260 J are required to vaporize it. To melt a solid (like ice), you need to use the enthalpy of fusion: **$\Delta H_{fus}$ of $H_2O$ is 334 J/g**. For each gram of ice at 0°C, there are 334 J of energy required to melt it.

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4. Verify that it takes 24,453 J of energy to heat 90 g of water from room temperature (35°C) to the boiling point (100°C). Recall that the specific heat ($C_p$) of water is 4.18 J/g°C. Show your work for credit on this problem.

5. Given the fact that $\Delta H_{vap}$ of water is 2260 J/g, we know that 2260 J of energy is required to vaporize 1 gram of water. To vaporize 2 grams of water, it requires 4520 J. For 3 grams, 6780 J are needed. Verify that it takes 203,400 J of energy to vaporize 90 g of water, when the water is already at its boiling point. Show your work for credit on this problem.

6. Verify that it takes 7272 J of energy to heat 90 g of steam from 100°C to 140°C. Note: the specific heat of steam ($C_p$) is 2.02 J/g°C. Show your work for credit on this problem.

7. Using only your answers to questions 4-6, calculate how many Joules of energy it takes to change 90 g of water at 35°C to steam at 140°C.

8. Calculate how many Joules of energy would be required to change 3785 g (5 gallons) of water at 85°C to steam at 110°C. You will need to break this problem into four steps:

   a) Find the Joules needed to heat the water to the boiling point. Think about what temperature water boils at.

   b) Find the Joules needed to vaporize the water.

   c) Find the Joules needed to heat the vapor (steam) from the boiling point to 110°C.

d) Add your answers from steps a, b, and c.

9. How much heat energy would be required to change the temperature of 18 g of ice from -68°C to liquid water at 68°C? *Hint: think about the steps you needed in problem 8.*