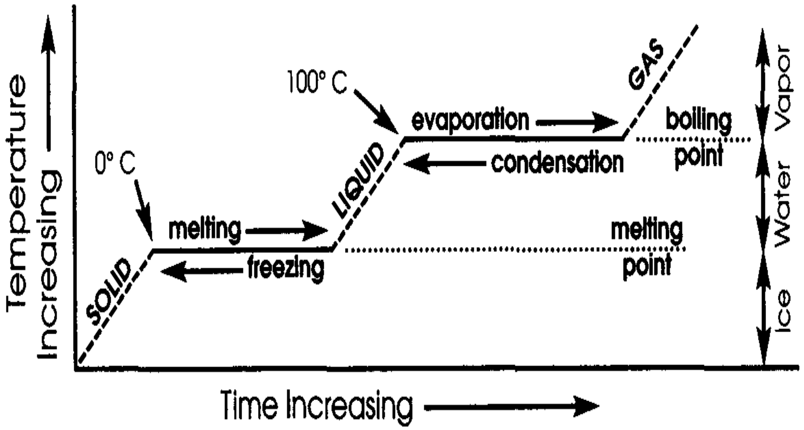
Section 13.4
Temperature-Energy Graphs

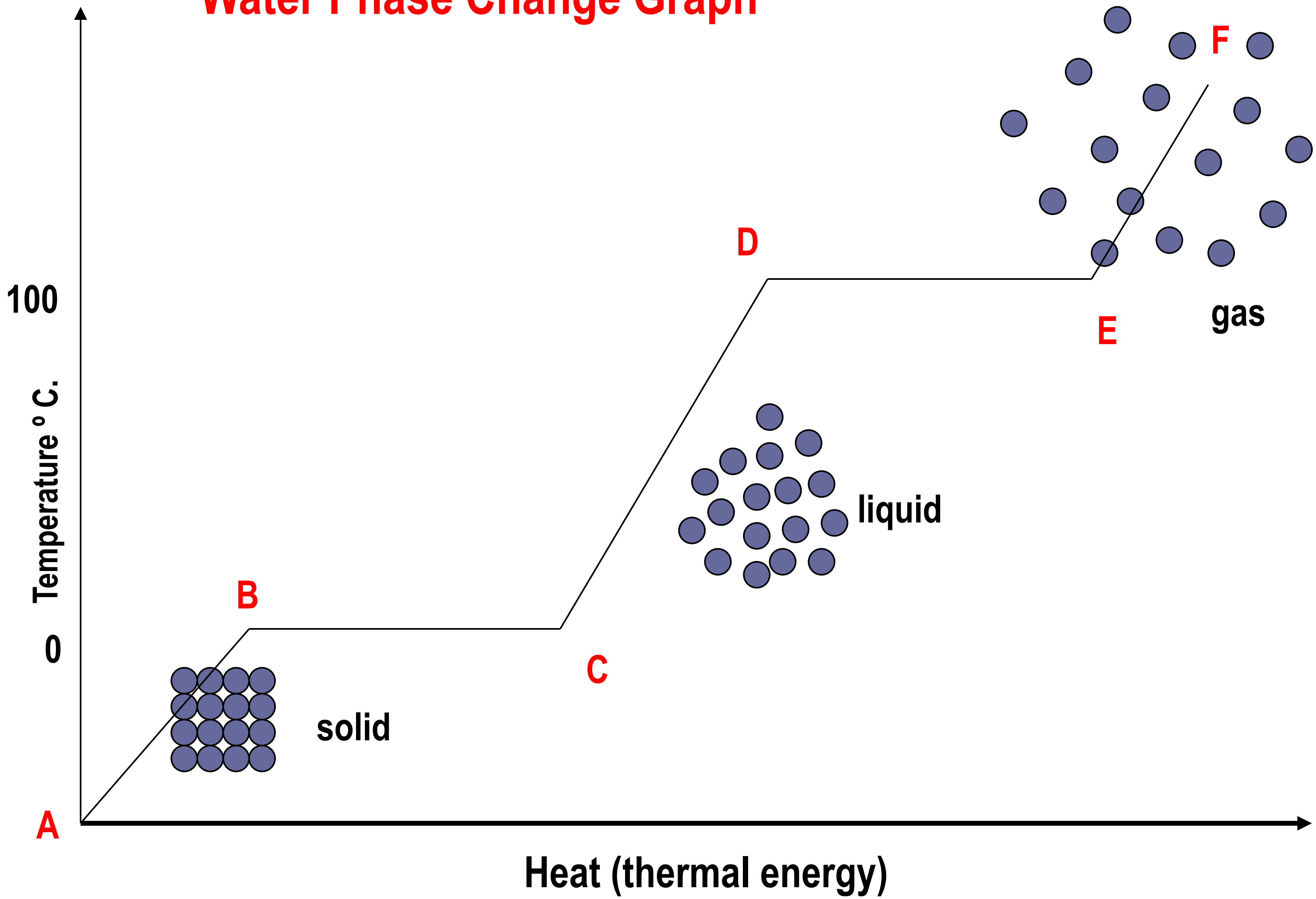


Phase Change Graph for Water

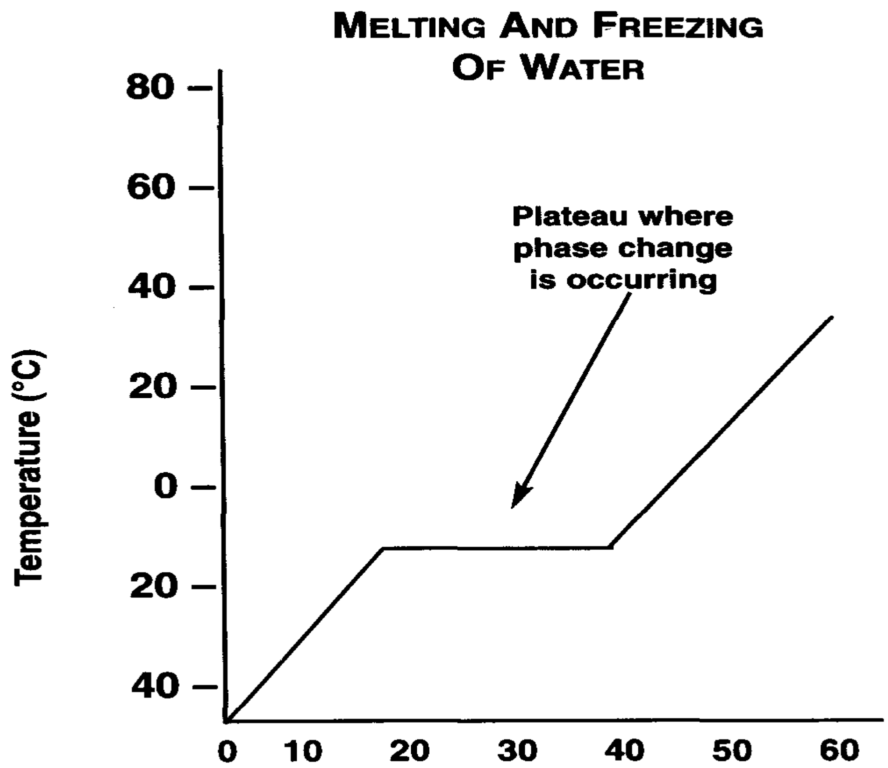
Temperature-Energy Graphs

A temperature-energy graph shows the energy and temperature changes as water turns from a solid, ice, to a liquid, water, and finally to a gas, water vapor.

Water Phase Change Graph

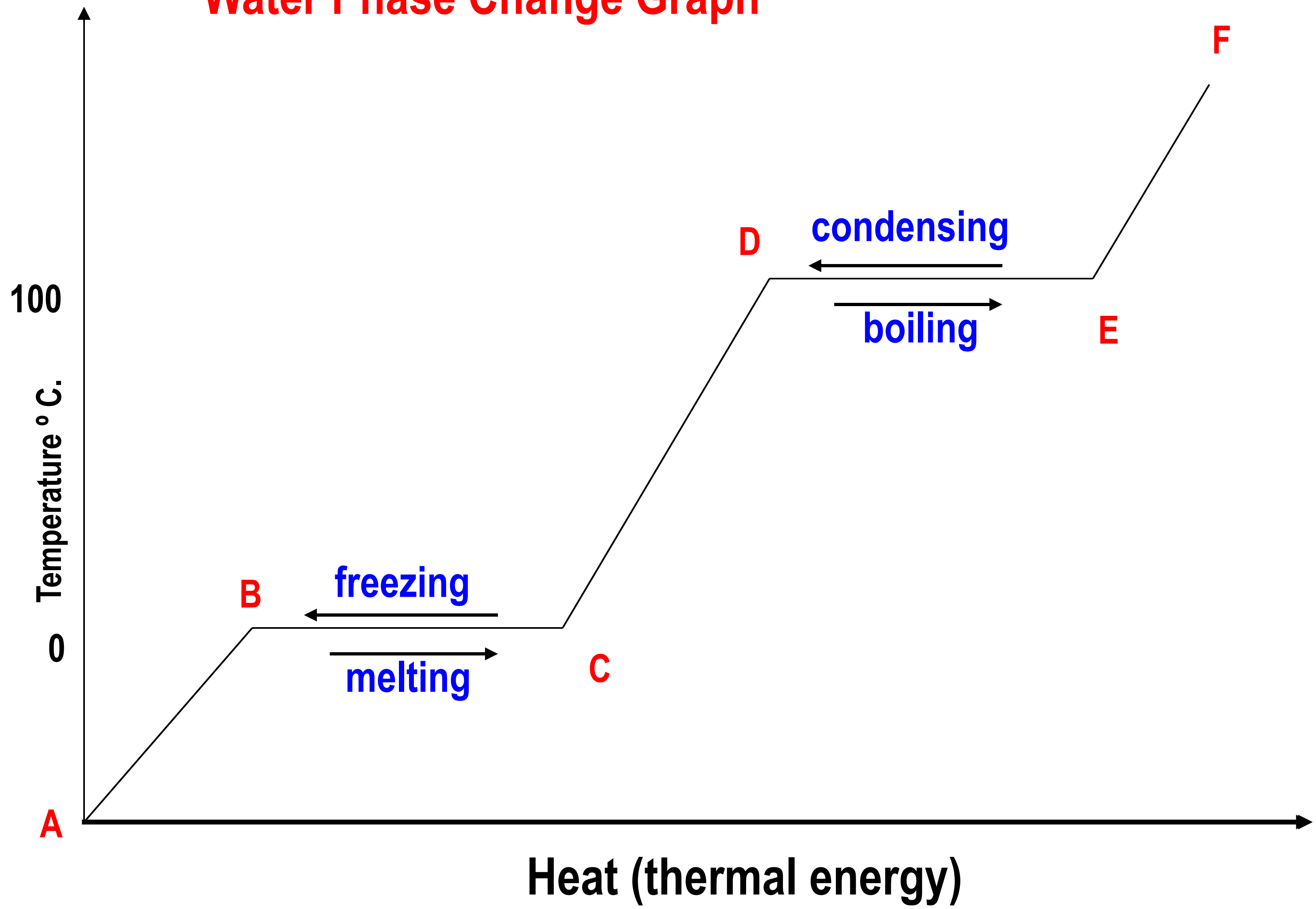


Phase Change Diagram – Flat Line



- Anytime there is a **flat line** on a temp-energy graph, a **phase change** is occurring.

Water Phase Change Graph



Temperature-Energy Graphs

Calculating Energy of a Phase Change

Heat of Fusion (solid - liquid)

Heat of Fusion:

The amount of energy absorbed or released when a substance melts or freezes.

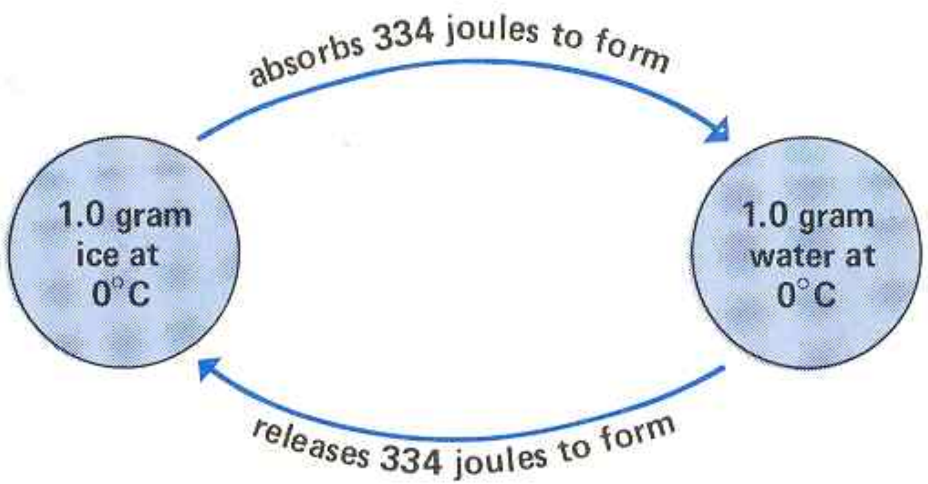
- **Symbol: L_F**
- **The L_F for water is 334 J/g**
- **This is the quantity of heat that must be absorbed by each gram of ice at 0°C to convert it to water at 0°C**
- **This is the quantity of heat that must be released from each gram of water at 0°C to convert it to ice at 0°C**

Heat of Fusion (solid - liquid)

Heat of Fusion:

- Varies for different substances
- All the energy is used to increase the potential energy of the particles. (Break bonds)
- Average kinetic energy doesn't change

Heat of Fusion (solid - liquid)



Heat of Fusion: $Q = m \cdot L_f$

Heat of Fusion

Heat

Mass

Heat of Vaporization (liquid – gas)

Heat of Vaporization:

The amount of energy absorbed or released when a substance boils or condenses.

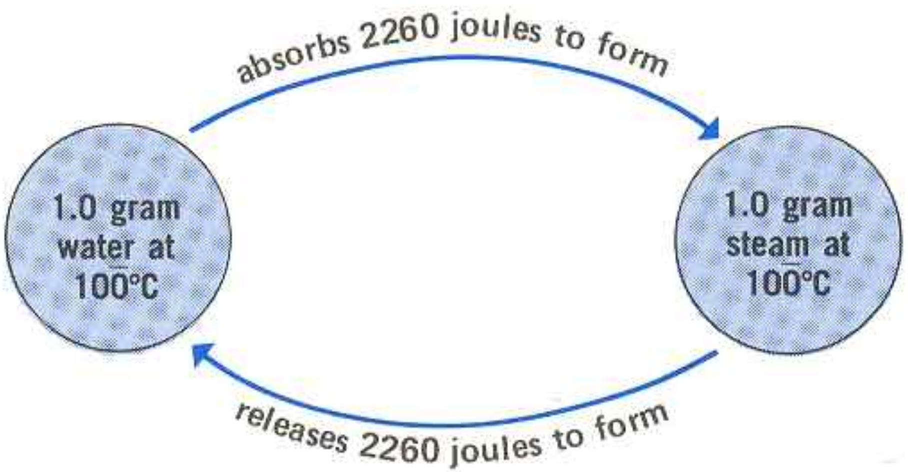
- Symbol: L_V
- The L_V for water is 2,260 J/g
- This is the quantity of heat that must be absorbed to each gram of water at 100°C to convert it to steam at 100°C
- This is the quantity of heat that must be released from each gram of steam at 100°C to convert it to water at 100°C

Heat of Vaporization (liquid – gas)

Heat of Vaporization:

- Varies for different substances
- All the energy is used to increase the potential energy of the particles. (Break bonds)
- Average kinetic energy doesn't change

Heat of Vaporization (liquid – gas)



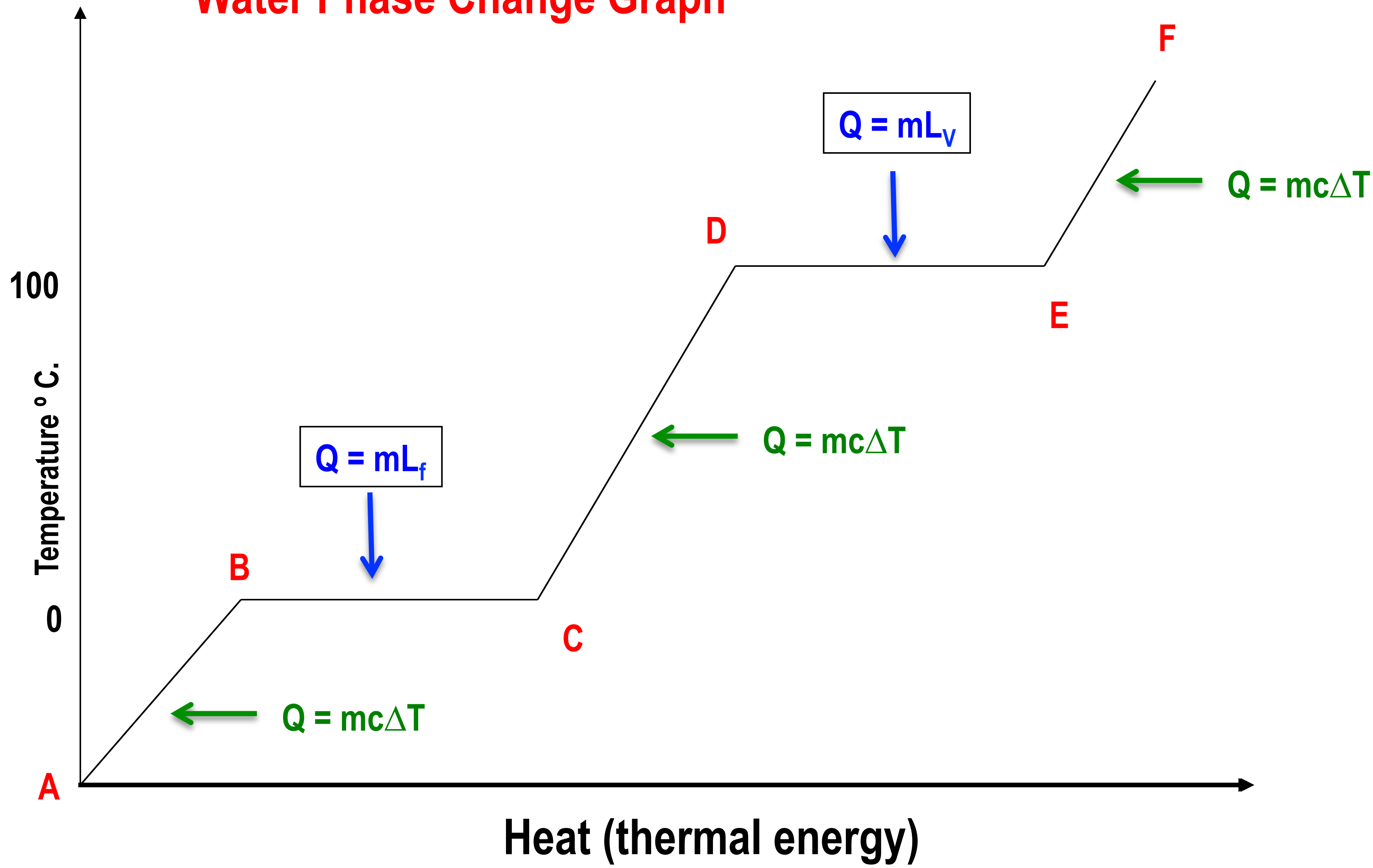
Heat of Vaporization: $Q = m \cdot L_V$

Heat

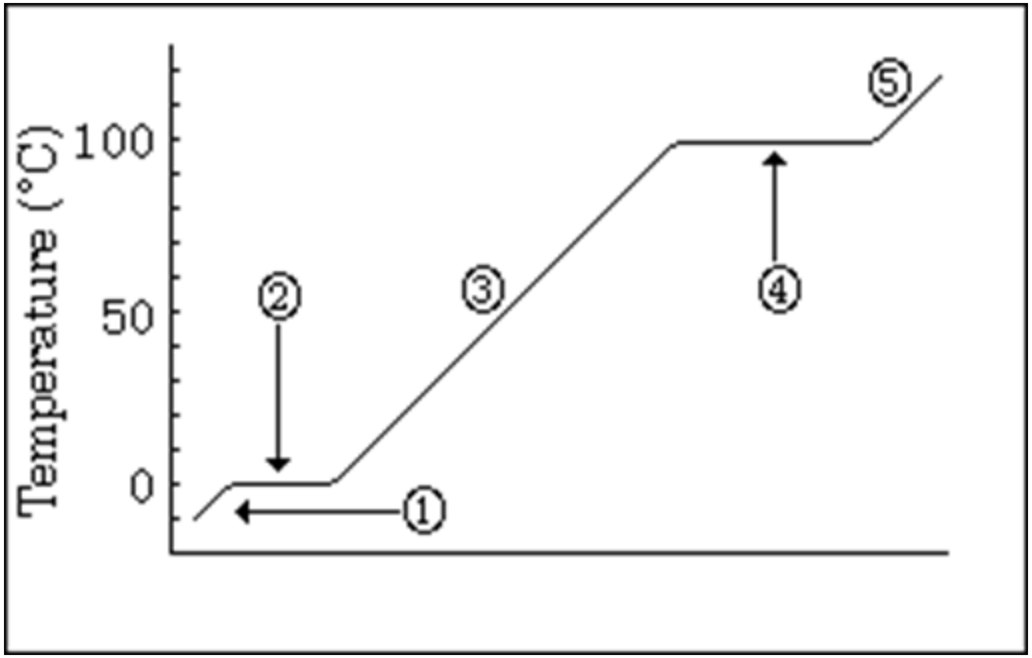
Heat of Vaporization

Mass

Water Phase Change Graph

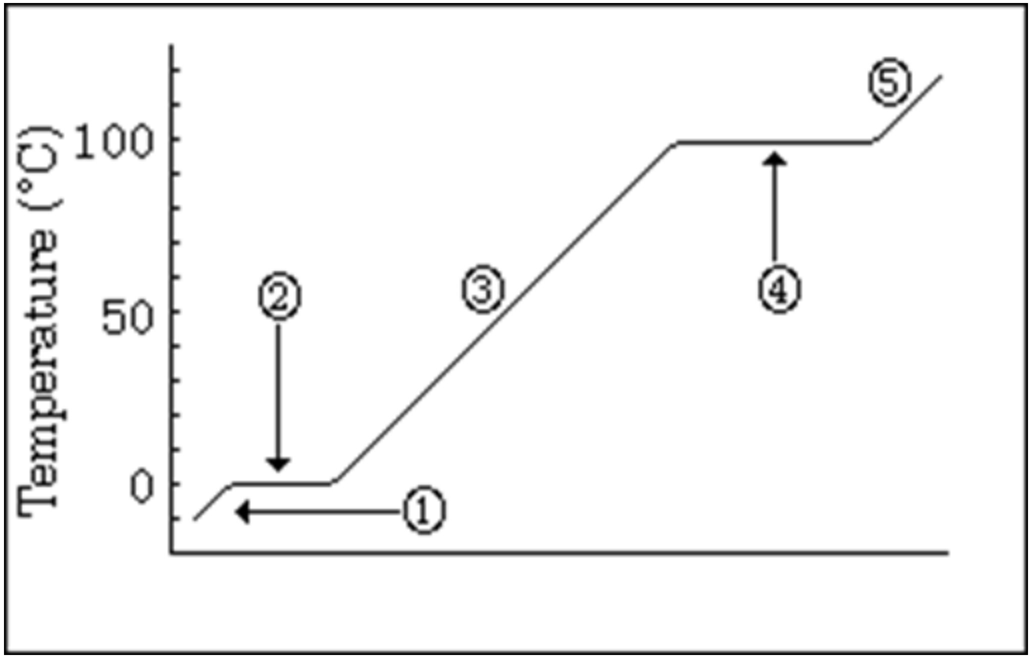


Calculating Energy



We are going to heat a container that has 72 grams of ice (no liquid water yet!) in it. To make the illustration simple, please consider that 100% of the heat applied goes into the water. There is no loss of heat into heating the container (That will come next) and no heat is lost to the air.

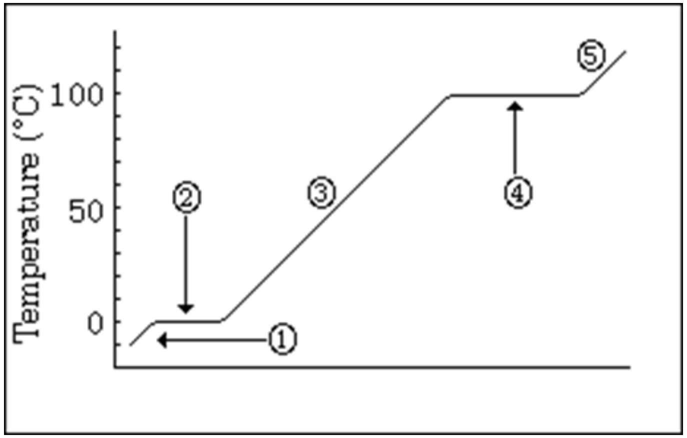
Calculating Energy



Let us suppose the ice starts at -10.0ºC and we want to add energy to end the example with steam at 120.0ºC.

There are five major steps to discuss in turn before this problem is completely solved. Here they are:

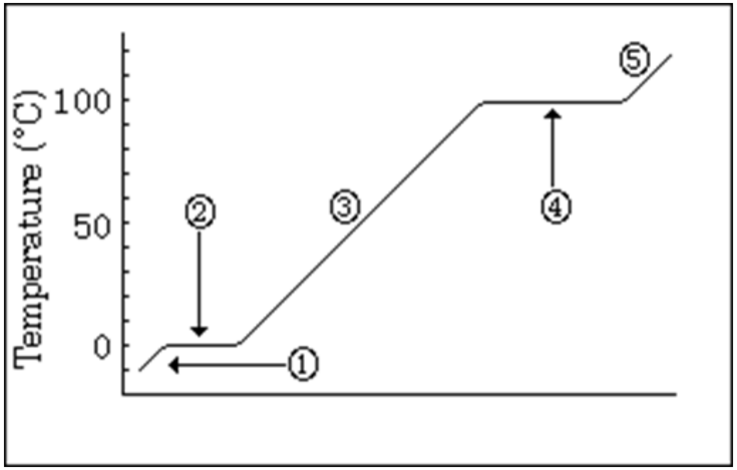
Calculating Energy



1. The ice rises in temperature from -10.0 to 0.00 ºC.
2. The ice melts at 0.00 ºC (Phase Change)
3. The liquid water then rises in temperature from zero to 100.0 ºC.
4. The liquid water then boils at 100.0 ºC (Phase Change)
5. The steam then rises in temperature from 100.0 to 120.0 ºC.

Each one of these steps will have an energy calculation associated with it.

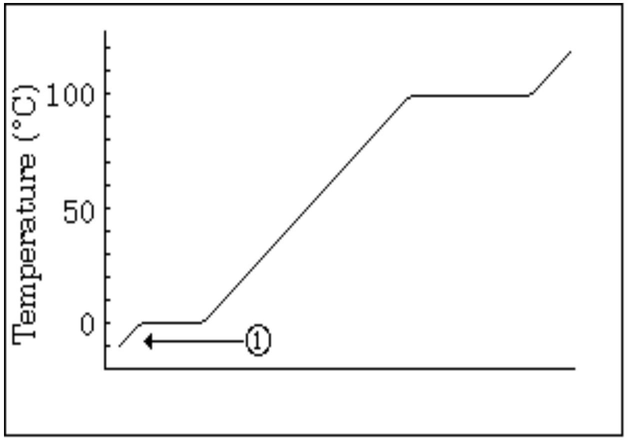
Calculating Energy



WARNING: many homework and test questions can be written which use less than the five steps. For example, suppose the water in the problem above started at 10.0 ºC. Then, only steps 3, 4, and 5 would be required for solution.

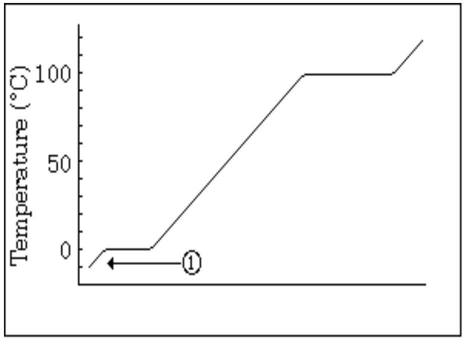
Also, note that numbers 2 and 4 are phase changes: solid to liquid in #2 and liquid to gas in #4.

Step 1: solid ice rises in temperature



- As we apply heat, the ice will rise in temperature until it arrives at its normal melting point of zero Celsius.
- Once it arrives at zero, the Δt equals 10 ºC. Δt = $(T_F\text{-}T_I)$
- Here is an important point: THE ICE HAS NOT MELTED YET.
- At the end of this step we have SOLID ice at zero degrees. It has not melted yet. That's an important point.
- Since ice is different substance than water, a different specific heat value is needed.

Step 1: solid ice rises in temperature



Energy Calculation

The calculation needed is used with the formula:

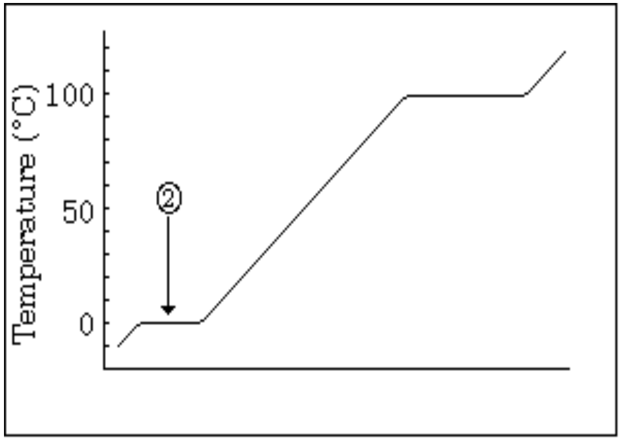
Q_1 = m C Δt : Δt = (T_F-T_I)

Q_1 = (72 g) (2.22 J/g ºC) (0 ºC -(-10 ºC))

So we calculate and get 1,598.4 J.

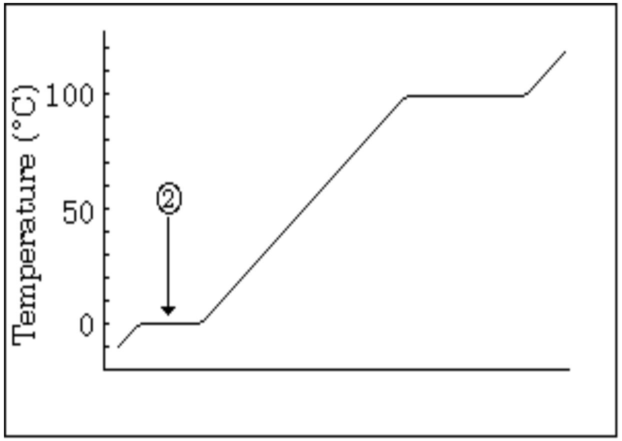
This is the energy to raise 72 g of ice from -10 ºC to 0 ºC

Step 2: solid ice melts (phase change)



- Now, we continue to add energy and the ice begins to melt.
- However, the temperature DOES NOT CHANGE. It remains at zero during the time the ice melts.
- During this time, the energy is being used to overcome water molecules' attraction for each other, destroying the three-dimensional structure of the ice.
- Energy calculation is the "heat of fusion"

Step 2: solid ice melts (phase change)



Energy Calculation

The calculation needed is used with the formula:

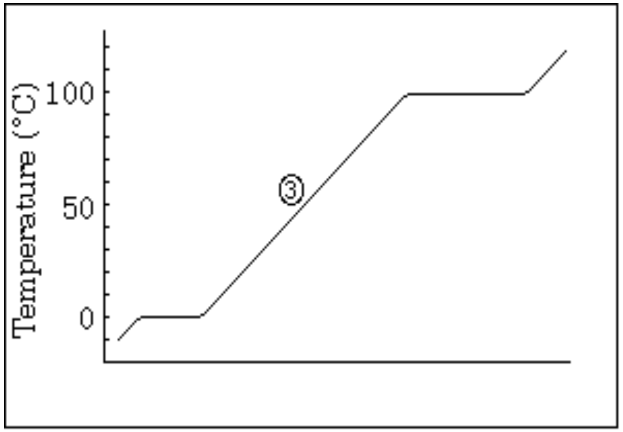
$Q_2 = m\, L_F$

$Q_2 = (72\ g)\ (334\ J/g)$

So we calculate and get 24,048 J.

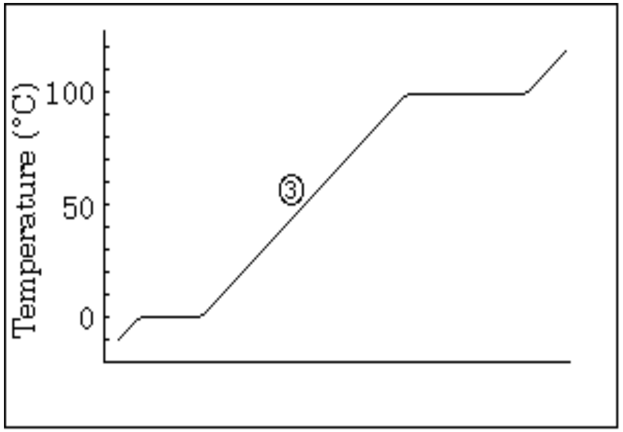
This is the energy required to melt 72 grams of ice.

Step 3: liquid water rises in temperature



- Once the ice is totally melted, the temperature can now begin to rise again.
- It continues to go up until it reaches its normal boiling point of 100 ºC.
- Since the temperature went from zero to 100, the Δt is 100. $\Delta t = (T_F - T_I)$
- Here is an important point: THE LIQUID HAS NOT BOILED YET.
- At the end of this step we have liquid water at 100 º. It has not turned to steam yet.

Step 3: liquid water rises in temperature



Energy Calculation

The calculation needed is used with the formula:

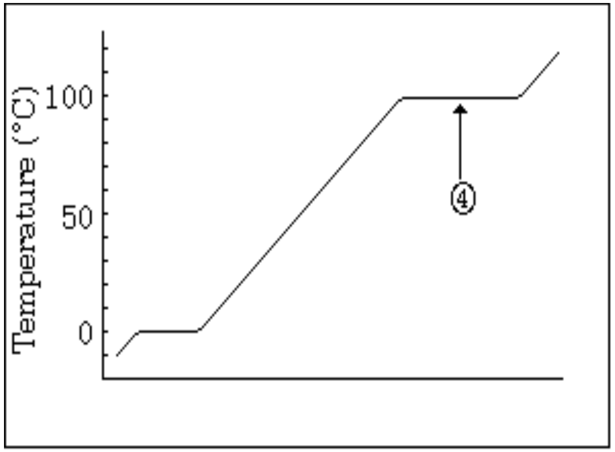
Q_3 = $m\ C\ \Delta t$: $\Delta t = (T_F - T_I)$

Q_3 = (72 g) (4.19 J/g ºC) (100ºC – 0ºC)

So we calculate and get 30,168 J.

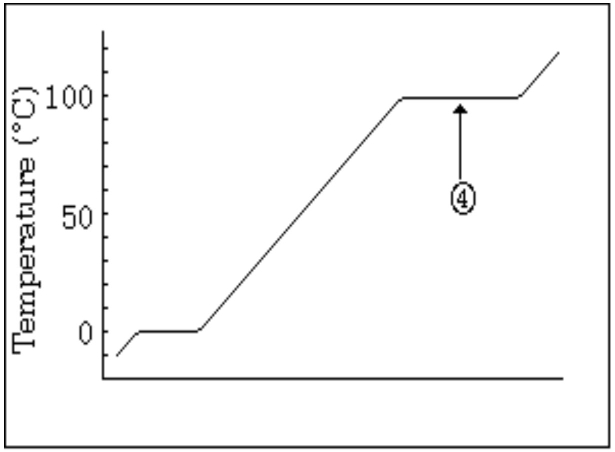
This is the energy required to raise 72 g of ice from 0º to 100º

Step 4: liquid water boils (Phase Change)



- Now, we continue to add energy and the water begins to boil.
- However, the temperature DOES NOT CHANGE. It remains at 100 during the time the water boils.
- During this time, the energy is being used to overcome water molecules' attraction for each other, allowing them to move from close together (liquid) to quite far apart (the gas state).
- Energy calculation is the "heat of vaporization"

Step 4: liquid water boils (Phase Change)



Energy Calculation

The calculation needed is used with the formula:

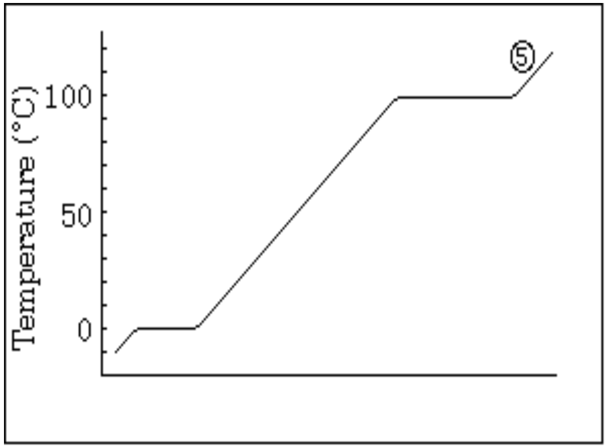
$Q_4 = m\ L_v$

$Q_4 = (72\ g)\ (2{,}260\ J/g)$

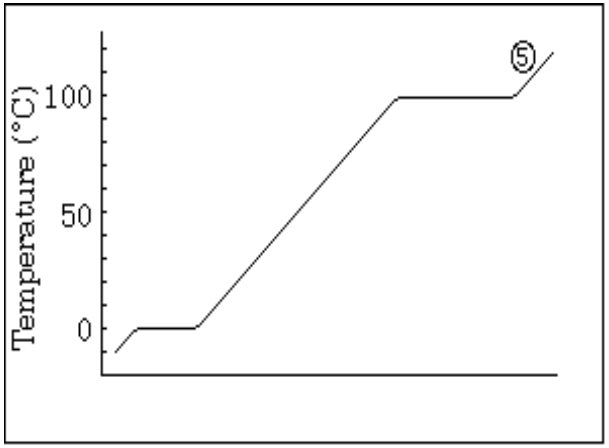
So we calculate and get 162,720 J.

This is the energy required to boil 72 grams of water.

Step 5: steam rises in temperature



- Once the water is completely changed to steam, the temperature can now begin to rise again.
- It continues to go up until we stop adding energy. In this case, let the temperature rise to 120 ºC.
- Since the temperature went from 100º to 120º, the Δt is 20º. $\Delta t = (T_F - T_I)$
- Since steam is different substance than water, a different specific heat value is needed.



Step 5: steam rises in temperature

Energy Calculation

The calculation needed is used with the formula:

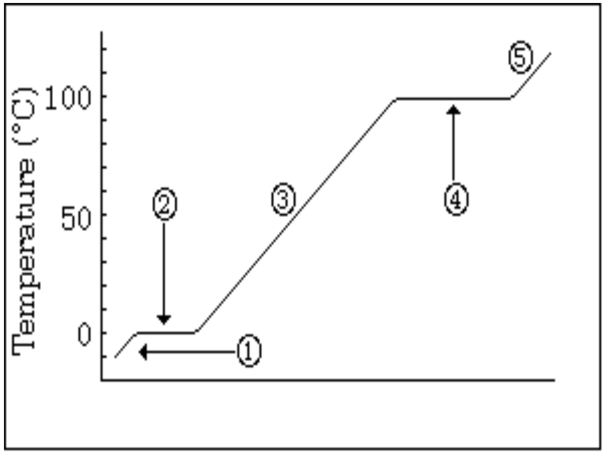
$Q_5 = m\ C\ \Delta t : \ \Delta t = (T_F - T_I)$

$Q_5 = (72\text{ g})\ (2.01\text{ J/g °C})\ (120\text{°C} - 100\text{°C})$

So we calculate and get 2,894.4 J

This is the energy required to raise 72 g of steam from 100ºC to 120ºC

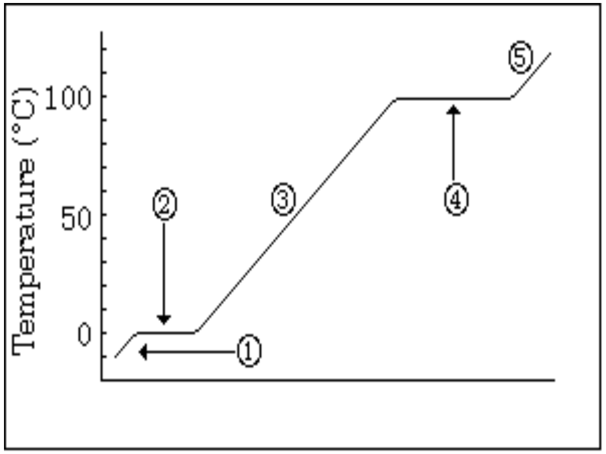
Final Step: Add all energy calculations together.



72.0 grams of ice has changed from -10.0 ºC to 120.0 ºC. The energy calculation for this change required five steps .

The following table summarizes the five steps and their results. Each step number is a link back to the explanation of the calculation.

[Final Step: Add all energy calculations together.]



72.0 grams of ice has changed from -10.0 ºC to 120.0 ºC. The energy calculation for this change required five steps .

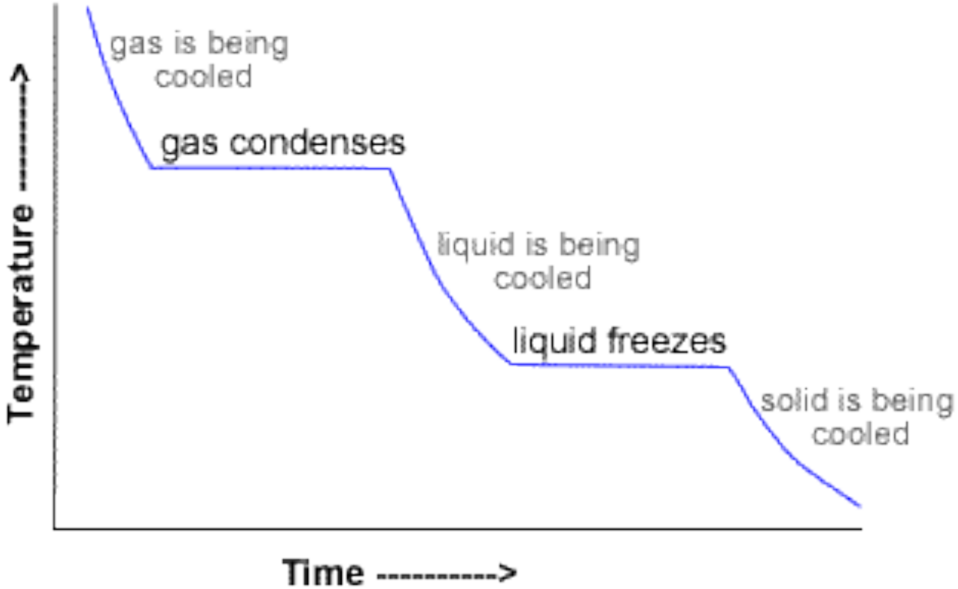
The following table summarizes the five steps and their results. Each step number is a link back to the explanation of the calculation.

Final Step: Add all energy calculations together.

Step	Description	Q	Energy
1	-10º to 0º (ice)	Q_1	1,598.4 J
2	melting (phase change)	Q_2	24,048 J
3	0º to 100º (water)	Q_3	30,168 J
4	Boiling (phase change)	Q_4	162,720 J
5	100º to 120º (steam)	Q_5	2,894.4 J

Total Energy (Q_{TOTAL}) = $Q_1 + Q_2 + Q_3 + Q_4 + Q_5$

Therefore it takes 221,428.8 J of energy to convert 72 grams of ice at -10.0 ºC to 120.0 ºC


gas is being cooled
gas condenses
liquid is being cooled
liquid freezes
solid is being cooled
Temperature ---------->
Time ---------->

Example #1

Calculate the energy required to raise the temperature of 12 grams of water from 22 ºC to 105 ºC.

167,365.44 J